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RANGE FINDERS AND RANGE FINDING.

By Commander F. J. Cleary, U. S. Navy, Member.

PREFACE.

This article has been prepared to present, in concise form, the more important points relating to range finders and range finding.

Part of the information contained herein is undoubtedly known to all officers who have used range finders to obtain ranges or who have studied the plotted ranges.

Other information, I believe, will be found to be either new, or presented in a new light.

No attempt has been made in this article to describe in detail any range finder. Such detailed description can be found in Ordnance Pamphlet 357, Range Finders, which was prepared under the direction of the Bureau of Ordnance.

SECTION I.—INTRODUCTORY.

For several years after the adoption of the new system of gunnery training for target practice and the use of a material target, range finders received little or no attention. This neglect was due to two readily understood causes:

1st. For the comparatively short ranges at which target practice was then held, the system of spotting was sufficiently accurate and spotting soon developed to a high degree of efficiency.

2d. The range finders then supplied the Navy were of a very short base length, none being greater than 4.5 feet in length. In addition to the inaccuracy inseparable from a short base length, they were of faulty mechanical and optical construction and, being purchased abroad, were not subject to adequate naval inspection either during manufacture or before acceptance.

The use of these range finders under actual service conditions afloat by officers interested in them, soon proved that they were very susceptible to derangement, often jarring out of adjustment during a run. Under the best conditions, the errors of the range finder exceeded those of the gun; and the error of a trained spotter in estimating the distance of a "short" or "over" was well within the error of the range of the target as determined by the range finder. Under these conditions, the use of the range finder was a waste of time and effort. Permanency of stations and adequate and continuous training for range finder crews were unheard of.

With the steadily increasing ranges of battle practice and the closer and closer approach to actual battle conditions under which the battle practices of the fleet were held, artificial aids to finding the range were gradually eliminated and it soon became apparent that spotting had its limitations and officers turned to the range finder as the most logical method of determining the range, if only as a first approximation for a sight bar range for trial shots.

A demand arose for an accurate range finder and in this field—as in all other fields—the demand resulted in development.

Some years ago, as a result of the wise policy of the fire control officer in the Bureau of Ordnance, Lieutenant Commander H. B. Price and the Chief of the Bureau, Rear Admiral N. E. Mason, the Bureau gave every aid and encouragement to the Bausch & Lomb Optical Company of Rochester, N. Y., to establish a range finder department.

The Bausch & Lomb Optical Company was especially well fitted for this development work, being, at that time, the only manufacturer in the United States with any extended experience in supplying optical instruments for the Bureau of Ordnance; in addition, the Bausch & Lomb Company was closely connected with the famous optical firm of Carl Zeiss of Jena, Germany, the foremost scientists in the optical world. A great part of the researches and developments of the Zeiss works thus became available for the use of the Bureau of Ordnance. The good faith and confidence of the Bausch & Lomb Company were shown in their first contract with the Bureau of Ordnance, in which the Bureau's acceptance of the range finders was conditioned on their being at least as accurate as any known instrument of equal base length.

The Bureau's encouragement of the Bausch & Lomb Company resulted in the establishment in the United States of a thoroughly equipped range finder factory as a source of supply in time of hostilities.

The value of a range finder establishment located in the United States has been shown by the present war which has prevented our purchasing any range finders abroad.

In time of peace, there are the advantages of efficient inspection during manufacture, of quick repair to damaged instruments and of experience and training for many officers and men who have had instruction in the Bausch & Lomb factory.

Our present range finders embody several new and valuable features, some of these due to The Carl Zeiss Company, others

to the Bausch & Lomb Company. A number of these features will be referred to in the following pages.

SECTION II.

THE ACCURACY OF RANGE FINDERS.

In actual practice, the accuracy of range finding depends upon several factors.

(1) Favorable working conditions, such as
  Minimum vibration,
  Protection of operator from wind or excessive heat or cold,
  Ease of handling of range finder.
(2) Skill of the operator.
(3) Nature of the object observed.
(4) Favorable atmospheric conditions; minimum smoke, haze or mirage.
(5) Length of base of the range finder.
(6) Magnification of the range finder.

If the observed object is clearly defined and the atmospheric conditions are favorable, the accuracy will depend upon the base length, which measures the angle of parallax at the target, and upon the smallness of the angle that the range finder is capable of measuring, which is a function of the magnification.

For instance, if ½ second of arc is the smallest angle that a range finder with a magnification M can detect, a range finder having a base length of 6 feet can distinguish between two objects at distances of 2,000 and 2,005 yards, respectively. A range finder having the same magnification, but with a base length of 12 feet, could distinguish between two objects at distances of 2,000 and 2,002.5 yards, respectively. In practice, the base length is limited by weight, convenience in handling and manufacturing difficulties; although in the last few

years range finders mounted on deck stands have increased in length of base from 4½ feet to 20 feet; turret range finders have a base length of 25 feet or more.

In figure 1, AB is the base of the range finder, C an object

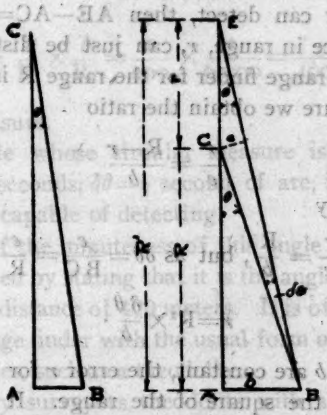


FIG. 1. FIG. 2.

at the minimum distance for which the range finder scale is graduated. Since AB is very short in comparison with AC, AC and BC can be considered equal and AB may be regarded as the arc of a circle of which the center is C. The circular measure of the angle θ is $\frac{AB}{AC} = \frac{\text{base}}{\text{minimum distance}}$. If we assume AB = 3 yards and AC = 500 yards;

$$\theta = \frac{3}{500} = \frac{6}{1{,}000} \text{ circular measure,}$$

or

$$\theta = 57.3^\circ \times \frac{6}{1{,}000} = 21 \text{ minutes of arc, approximately.}$$

For a base length of 3 yards, this small angle θ is the whole angle available for measuring all ranges from 500 yards to infinity.

In the same way, we find that the angle available for measuring all ranges between 1,000 yards and infinity for range finders of 9-foot and 15-foot bases is respectively 10 minutes of arc and 17 minutes of arc.

In figure 2, let CBE or $\delta\theta$ represent the smallest angle that the range finder can detect, then $AE-AC=CE=r$.

This difference in range, r, can just be distinguished and the error of the range finder for the range R is $\pm r$.

From the figure we obtain the ratio

$$\frac{r}{e}=\frac{R-r}{b}$$

or approximately

$$\frac{r}{e}=\frac{R}{b}, \text{ but as } \delta\theta=\frac{e}{BC}=\frac{e}{R}$$

$$r=R^2\times\frac{\delta\theta}{b}.$$

Since $\delta\theta$ and b are constant, the error r for the range R is proportional to the square of the range. It follows that a range finder with an error of 30 yards at a range of 6,000 yards will have at

1,000 yards, an error of $\frac{1}{6}$ yard,
2,000 yards, an error of $3\frac{1}{3}$ yards,
3,000 yards, an error of $7\frac{1}{2}$ yards,
12,000 yards, an error of 120 yards.

Since $r=R^2\times\frac{\delta\theta}{b}$ (and as $\frac{\delta\theta}{b}$ is a constant) $\frac{r}{R}$ varies as R, which shows that the percentage of error varies as the range and a range finder that has an error of $\frac{1}{2}$ of 1 per cent at 6,000 yards will have an error of

$\frac{1}{6}$ of 1 per cent at 2,000 yards,
$\frac{1}{20}$ of 1 per cent at 600 yards,
1 per cent at 12,000 yards.

This equation for r can be written in the form $\delta\theta=\frac{rb}{R^2}$,

If we take as the standard of accuracy $\frac{r}{R}$ within $\frac{1}{2}$ of 1 per cent at 6,000 yards for a base length of 3 yards, then

$$\frac{r}{R} = \frac{\frac{1}{2}}{100}$$

and,

$$\delta\theta = \frac{r}{R} \times \frac{b}{R} = \frac{1}{200} \times \frac{3}{6{,}000} = \frac{1}{400{,}000}$$

in circular measure.

As the angle whose circular measure is unity contains about 206,000 seconds, $\delta\theta = \frac{1}{2}$ second of arc, is the angle the range finder is capable of detecting.

Some idea of the minuteness of this angle of ½ second of arc can be gained by stating that it is the angle subtended by 1 millimeter at a distance of 400 meters. It is of interest to compare such a range finder with the usual form of instrument for measuring angles, such as a theodolite.

The ordinary surveyors theodolite with a 5-inch circle is graduated to read by vernier to 1 minute of arc. In order to read to ½ second of arc with equal facility, a graduated circle 50 feet in diameter would be required.

Although the range finder may be capable of *measuring* an angle of ½ second of arc, the eye can resolve such an angle only when it is sufficiently magnified.

Years of practical experience with range finders of the coincidence type have proved that under the most favorable conditions the unaided eye cannot resolve angles of less than 10 seconds of arc in making a coincidence of the two halves of an object and it is advisable to consider the value of this angle between 12 seconds and 15 seconds (12 seconds is the value used in figuring errors in this article. In the range finder pamphlet a slightly smaller value is assumed for this angle).

Accordingly, it would be necessary to use a magnification of about 30 diameters to enable the eye to resolve this angle of ½ second of arc.

As previously stated, this type of range finder is based upon the determination of the angle θ subtended at the target by the base length of the range finder.

Referring again to Figure 2, we have

$$\theta = \frac{AB}{AC} = \frac{b}{R}$$

in circular measure.

$$\theta = \frac{b}{R} \times 206{,}000 \text{ seconds.} \qquad (1)$$

In the case of a range finder with unit magnification the measurement of the angle θ is accompanied by an error $\delta\theta$ depending upon the observer's keenness of vision, the nature of the target, the atmospheric conditions and the optics of the range finder.

The angle thus measured

$$\theta \pm \delta\theta = \theta'$$

gives a wrong range R' and

$$R' = R \pm r$$

$$\theta' = \frac{b}{R'} \times 206{,}000 \text{ seconds.} \qquad (2)$$

Subtracting equations (1) and (2)

$$\theta - \theta' = \pm\delta\theta = b\left(\frac{1}{R} - \frac{1}{R'}\right)206{,}000,$$

$$= b\left(\frac{R' - R}{RR'}\right)206{,}000,$$

$$R' - R = r = \frac{\pm\delta\theta\, RR'}{b\ 206{,}000}.$$

As the error r is usually small in comparison with R, R^2 can be substituted for RR' and

$$r = \frac{\delta\theta\, R^2}{b} \times \frac{1}{206{,}000}. \qquad (3)$$

This equation shows that the error, r, increases with the angular error, $\delta\theta$, and with the square of the range, R, but decreases with increase of base length, b.

If we assume

$b=3$ yards, $R=1{,}000$ yards, $\delta\theta=12$ seconds,

then by the use of equation (3)

$$r=R-R'=\frac{12\times 1{,}000\times 1{,}000}{3\times 206{,}000}=19.4 \text{ yards.}$$

When $R=3{,}000$ yards we have,

$$r=\frac{12\times 3{,}000\times 3{,}000}{3\times 206{,}000}=175 \text{ yards}$$

Now if the range finder has a magnification of V, the angular error $\delta\theta$ is reduced in direct ratio to the magnification and instead of the error $\delta\theta$ we have $\frac{\delta\theta}{V}$.

Equation (3) then becomes

$$r=\frac{\delta\theta R^2}{V b}\times\frac{1}{206{,}000}. \quad (4)$$

It is thus possible to reduce the error, r, by increasing the magnification, V.

A limit, however, to the increase of V is soon reached by the excessive mirage inseparable from high magnification, by optical difficulties and by the decreased field; so that a magnification of 28 or 30 diameters has been found to be the upper limit under service conditions, and it has been found necessary to provide range finders with a lower magnification of about 15 diameters as well, for night use or with poor light or excessive mirage.

Equation (4) is used in calculating the tables of minimum errors for range finders, using the value $\delta\theta=12$ seconds; (the base length, b, and the range, R, being expressed in yards).

It should be remembered that these errors have been calculated for favorable conditions.

Under unfavorable conditions (glaring light, excessive mirage, poorly defined objects, etc.) the errors of measurement sometimes amount to six times the calculated errors; but an average error of double the calculated error must be expected.

TABLE OF ERRORS.

Base length 3 meters; Magnification 28 diameters.

Range in yards.	*Minimum Error in yards.*	*Expected Error (Favorable conditions).*
1,000	.6	1
2,000	3.0	6
3,000	6.0	12
4,000	10.0	20
5,000	16.0	32
6,000	23.0	46
7,000	31.0	62
8,000	40.0	80
10,000	62.0	124
12,000	90.0	180
15,000	140.0	280

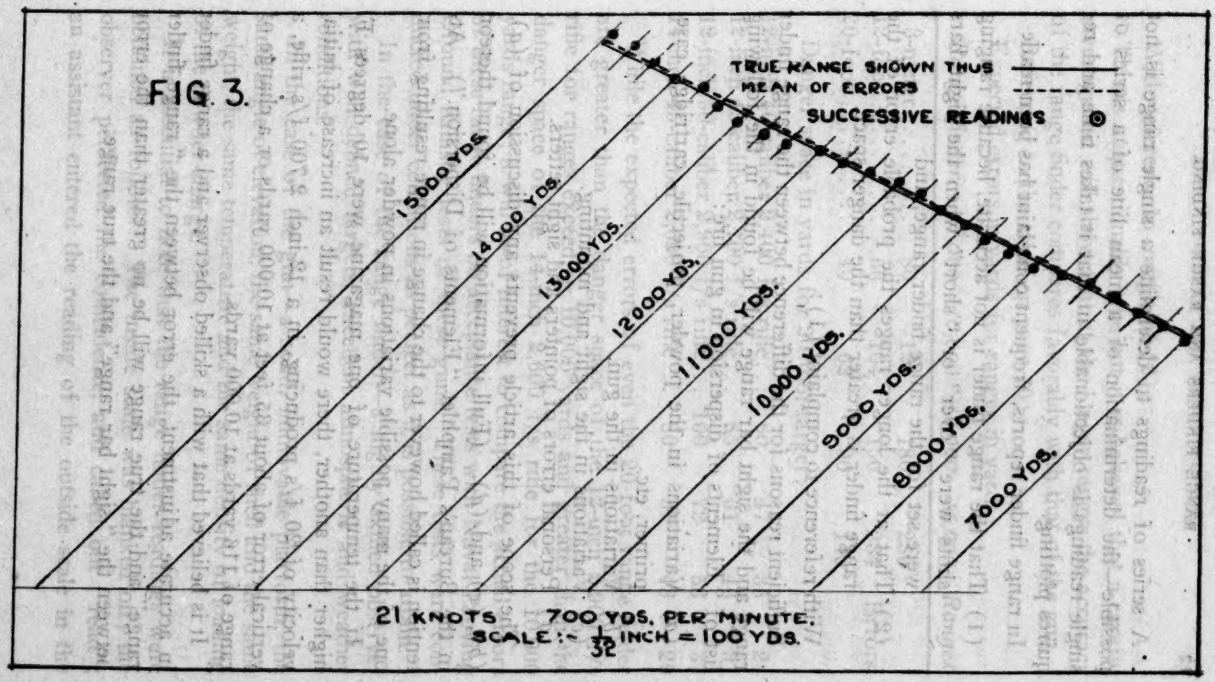
This "Expected Error" is the error for single observations. The range obtained by a skilled range finder operator on a single observation of a well defined target under favorable conditions will lie between two extremes,

i.e., the true range + the expected error and
the true range — the expected error.

For instance, for a true range of 15,000 yards his reading might be 15,280 yards, or 14,720 yards and he might obtain any intermediate range. Two consecutive readings might give the same range but the chance is equal that they might give the two extremes possible. If a series of readings were taken on a target whose range was not changing, or was changing very slowly, the mean of these readings would be very close to the true range.

If the range is changing rapidly it is not possible to take a series of readings to determine one range, but by taking successive readings and carefully plotting each position by gyro compass bearings a line can be obtained which will be a close approximation to the mean of all the ranges (Fig. 3).

FIG. 3.


TRUE RANGE SHOWN THUS
MEAN OF ERRORS
SUCCESSIVE READINGS
15000 YDS.
14000 YDS.
13000 YDS.
12000 YDS.
11000 YDS.
10000 YDS.
9000 YDS.
8000 YDS.
7000 YDS.
21 KNOTS 700 YDS. PER MINUTE.
SCALE :- 1/32 INCH = 100 YDS.

A series of readings to determine a single range is not possible—the determination of a mean line of a series of single readings is objectionable in that it takes time and requires plotting.

In range finder reports, frequent complaint has been made

(1) That the range finder is not accurate, because ranging shots were "over" or "short" when the sight bars were set for the range finder range, and

(2) That at the longer ranges the probable error of the range finder is greater than the danger space.

With reference to complaint (1):

Sufficient reasons for the difference between the range finder range and the sight bar range will be found in the following list of "Elements of dispersion in gun fire:"

(*a*) Variations in the powder, projectile, cartridge case, primer, etc.

(*b*) Variations in the gun.

(*c*) Variations in the sight and mounting.

(*d*) Personal errors of pointers and sight setters.

The scope of this article prevents any discussion of (*a*), (*b*), (*c*) and (*d*). (Full information will be found thereon in the Bureau's Pamphlet "Elements of Dispersion.") Attention is called however to the change in range resulting from one of the many possible variations in powder alone.

If the temperature of one magazine were 10 degrees F. higher than another, there would result an increase of initial velocity of 20 f/s producing, in a 12-inch 2,700 f/s rifle, a vertical error of about 35 feet at 10,000 yards or a change of range of 116 yards at 10,000 yards.

It is believed that with a skilled observer and a range finder in accurate adjustment, the error between the "range finder range" and the true range will be no greater than the error between the "sight bar range" and the true range.

With reference to complaint (2):

This is unquestionably true but it is believed that a careful investigation will show that at the longer ranges the accuracy of the range finder compares favorably with that of the gun.

Referring to the table on page 10:

Expected errors in yards for ranges in yards:

Range finder.	*8,000*	*10,000*	*12,000*	*15,000*	*Ranges.*
3-meter	80	124	180	280	
12-foot	66	104	150	234	Errors.
20-foot	40	62	90	140	

Danger space in yards for 20-foot target:

12-inch 40-caliber 2,400 f/s rifle...	60	47	35	24
12-inch 45-caliber 2,700 f/s rifle...	85	61	46	31
12-inch 50-caliber 2,900 f/s rifle...	100	72	53	37
14-inch 45-caliber 2,600 f/s rifle...	80	57	43	29

While the expected errors of even the 20-foot range finder are greater than the danger space of the 12-inch 2,900 f/s rifle for ranges exceeding 10,000 yards and greater than the danger space of the 14-inch 2,600 f/s rifle for the 10,000 yards range; it will be of interest to compare the actual errors of these range finders on acceptance tests with Naval Proving Ground ballistic tests of these guns. These tests were conducted under conditions as perfect as it is possible to attain.

In the case of the range finder—a highly skilled observer with well defined targets, excellent atmospheric and weather conditions.

In the case of the gun—a solid, immovable platform, the same angle of elevation, the same weight of shell and the same weight, the same temperature and the same density of loading of the powder charge.

It is essential to note that the range finder readings were obtained as follows: The inside scale was blanked off; the observer perfected the coincidence, and called out "read"; an assistant entered the reading of the outside scale in the

record book without informing the observer of the reading. In this way a series of readings on one object would be obtained. The range finder was then trained upon a second target and a series of readings obtained for the second target. After all targets had been ranged on, the observer compared the readings obtained with the permissible acceptance errors. If the range finder was within the limiting errors permitted in the specifications, it was set aside to be given a similar test on a later day and if it was again within the limiting errors on the second test it was accepted. If it fell down on either test, readjustment by the contractors was required until it passed on two successive tests.

Of the two instruments, the 3-meter range finder readings are more consistent and the maximum errors are smaller; being probably due to slightly better and more uniform atmospheric conditions.

Acceptance test of
3 Meter Range Finder Mark IV, Mod. 5, No. 79.

(All distances are in yards.)

True ranges.	*4,600*	*5,550*	*8,300*	*10,240*	*10,500*	*16,600*
	4,590	5,540	8,370	10,350	10,650	16,600
	4,600	5,580	8,200	10,350	10,600	16,500
Range Finder	4,605	5,580	8,280	10,200	10,550	16,450
Readings	.....	.....	8,275	10,225	10,600	16,450
	.....	.....	.....	.....	10,550	.....
	.....	.....	.....	.....	10,550	.....
	13,795	16,700	33,125	41,125	63,500	66,000
Mean	4,598	5,567	8,281	10,281	10,583	16,500
Mean error....	2	17	19	41	83	100
Maximum error	10	30	100	110	150	150

Acceptance test of

12 Foot Range Finder Mark XII, No. 13.

(All distances are in yards.)

True ranges.	*4,600*	*5,550*	*8,300*	*10,240*	*10,500*	*16,600*
	4,605	5,555	8,300	10,050	10,600	16,500
	4,615	5,600	8,350	10,320	10,350	16,400
	4,620	5,640	8,280	10,100	10,690	16,700
Range Finder	4,585	5,535	8,295	10,100	10,675	16,450
Readings	.....	5,550	8,200	10,150	10,700	16,800
	.....	.....	8,410	10,200	10,575	16,750
	.....	.....	.....	10,300	10,525	16,350
	.....	.....	.....	10,100	.....	.....
	18,425	27,880	49,835	81,320	74,115	115,950
Mean	4,606	5,576	8,306	10,165	10,588	16,564
Mean error....	6	26	6	75	88	36
Maximum error	20	90	110	190	200	250

SECTION III.

TYPES OF RANGE FINDERS.

There are several types of range finders, some of them, while not suitable for naval use, being especially adapted for special conditions ashore.

The various types are:

Depression.

Long base, two observer.

Single observer, self-contained base, stereoscopic.

Single observer, self-contained base, coincidence, inverted image.

Single observer, self-contained base, coincidence, erect image.

The Depression Range Finder (Fig. 4) is used extensively

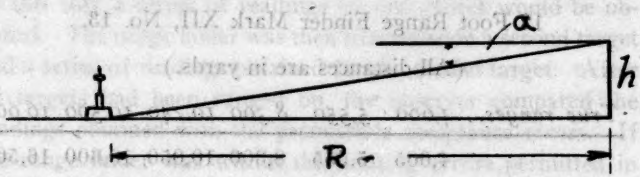


FIG. 4.

by the coast artillery and is simple in principle, being based on the angle α measured between the water line of the target and the horizontal plane; this angle with the known height, *h* (corrected for the tide), gives the range, R.

At long ranges, the smallness of the angle α, together with the uncertainty due to refraction near the horizon, affects the accuracy of this method.

The long base two-observer range finder (Fig. 5) is also

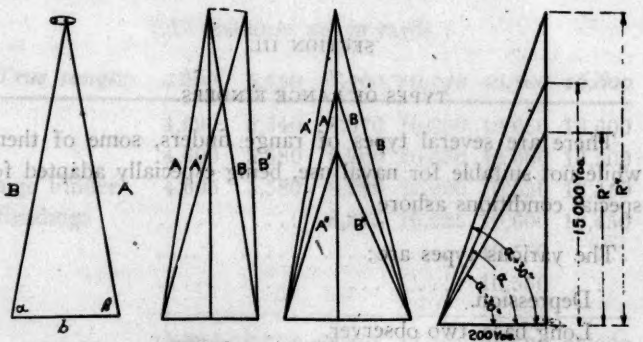


FIG. 5. FIG. 6. FIG. 7. FIG. 8.

used extensively by the coast artillery and is based on the principle of a long base, *b*, of known length with an accurate instrument at each extremity of the base for measuring the

angles α and β and thereby determining the distance A or B which, by suitable corrections, is reduced to the range from the battery.

It is obvious that the accuracy of this method depends upon three conditions:

(*a*) The variation from a 90-degree angle between the base line and the target line of bearing from the center of the base.

(*b*) The simultaneous reading of the angles α and β.

(*c*) The personal error of the two observers, or the accuracy with which the vertical cross line of the telescope is placed upon the designated point of the target.

It is apparent that the personal error of the two observers may greatly affect the accuracy with which the range is determined.

If the personal errors of the two observers were equal in amount and made in the same direction, say to the right, the effect would be as shown (exaggerated) in Figure 6.

Under this condition, unless the personal errors were excessive, the difference between the true range and the measured range from the target to the base line would be inconsiderable.

If, however, the personal errors were made in opposite directions the effect would be as shown (exaggerated) in Figure 7 and the difference between the true range and the measured range might be considerable.

No data exists as to the probable personal error in such a case. When it is considered that the requirement of simultaneous observations at each end of the base necessarily demands taking the angles on signal, that the target is moving and may be poorly defined or partly obscured by smoke, it appears reasonable to assume this probable personal error as 30 seconds of arc under unfavorable conditions.

This error of 30 seconds of arc is assumed for the following reasons: On page 7 it was stated that the unaided eye cannot resolve angles of less than about 12 seconds of arc in

making a coincidence of the two halves of an image. It must be understood that this degree of accuracy of the resolving power of the eye applies only to observations of coincidence where the partial images of the object are separated by a fine line and the adjustment is made by bringing the partial images into exact alignment at the separating line. Under such conditions the eye is capable of distinguishing with great exactitude any discontinuity or error in alignment even when the definition of the edges of the object is not perfect. In the case of overlapping or superposition of images or in placing a cross line of finite width on a designated point of aim, the smallest angle that the eye can resolve is more than twice the above value of 12 seconds of arc even under ideal conditions and, in practice, when the edges of the images are not perfect or where the cross line is heavy or ragged it is not possible to determine, with the necessary degree of accuracy, when the images are correctly superposed.

With a base length of 1,200 feet and a true range of 15,000 yards, this applied personal error of 30 seconds would give the following results (Fig. 8):

$\text{Cot}\ \alpha = \frac{200}{15{,}000}$	lg	2.30103		
	lg	4.17609		
$\alpha = 89°\ 14'\ 10''$		8.12494		
200	lg	2.30103	lg	2.30103
$\alpha - 30$ seconds $= 89°\ 13'\ 40''$	Cot	8.12963		
$\alpha + 30$ seconds $= 89°\ 14'\ 40''$			Cot	8.12014
$R' = 14{,}839$ yds.		4.17140		
$R'' = 15.167$ yds.				4.18089

a possible mean error of 164 yards at 15,000 yards range due to this cause.

The two-observer long-base range finder has two advantages ashore that it would not possess afloat. These are—a base of any desired length and a stable platform.

In view of the fact that the question of the use afloat of a two-observer long-base range finder is periodically revived in the Navy, it will be of interest to state here the comparative results obtained by the coast artillery with the three types: depression, two-observer long-base, and single-observer erect-image coincidence range finders.

At all coast artillery posts equipped with the three types of range finders, extensive series of ranges were taken by the range finders on fixed and on moving targets under varying conditions. At the same time the true ranges of the targets were obtained by triangulation, by plotting the course of the target on the chart, etc. These recorded ranges, of which there were several thousand, were forwarded to the Artillery School at Fortress Monroe, where they were analyzed and the errors calculated.

Lt. Col. Albert L. Rhoades, C. A. C., U. S. Army, is my authority for stating that these results showed the comparative accuracy of these three types of range finders (reduced to the same length of base) to be as follows:

Single Observer Erect Image Coincidence.	Depression.	Two Observer Long Base.
1	$\frac{1}{5}$	$\frac{1}{60}$

The following is quoted from his report:

"The ratios of lengths of base for equal accuracy of the different types of range finders are:

Single-observer erect-image coincidence, 1 foot;
Depression position finder, vertical base, 5 feet;
Two-observer long horizontal base, 60 feet.

"In other words, the 20-foot self-contained base single-observer erect-image coincidence range finder, the depression range finder with a 100-foot vertical base, and the two-observer long horizontal base range finder with a 1,200-foot horizontal base, are of equal accuracy.

"I believe that it will only be a question of a short time when I will have to modify these ratios on account of the increased accuracy we are getting with the coincidence range finder, which is largely due to a better selection and training of observers."

SINGLE-OBSERVER SELF-CONTAINED BASE RANGE FINDERS.

The more important advantages possessed by this type of range finder are:

Requires only one observer.

The ranges of moving objects can be observed continuously.

The accuracy of the range obtained is independent of the bearing of the target.

The smaller types of range finders can be set in any position; horizontal, inclined or vertical, enabling a coincidence to be obtained of lines other than vertical.

Great convenience, simplicity, and rapidity of operation.

SINGLE-OBSERVER STEREOSCOPIC RANGE FINDER.

It is well known that objects at a distance viewed through a telescope or other monocular all appear to lie in a plane equidistant from the observer. When these same objects are viewed through a binocular the image acquires depth, or a relief effect, which enables the observer to distinguish the relative distances of the objects from him.

The stereoscopic range finder is based upon this principle of binocular vision greatly amplified by separating the end prisms of the instrument to a distance of about 60 inches. The stereoscopic range finder is similar to the Mark I Spotting Glass with the addition of a range scale in the image plane of each eye piece. The appearance of the field of this range finder is illustrated in Figure 9.

As shown, the scale is projected stereoscopically into the field and, by observing the image of the target with reference to the range scale, its distance can be quickly determined.

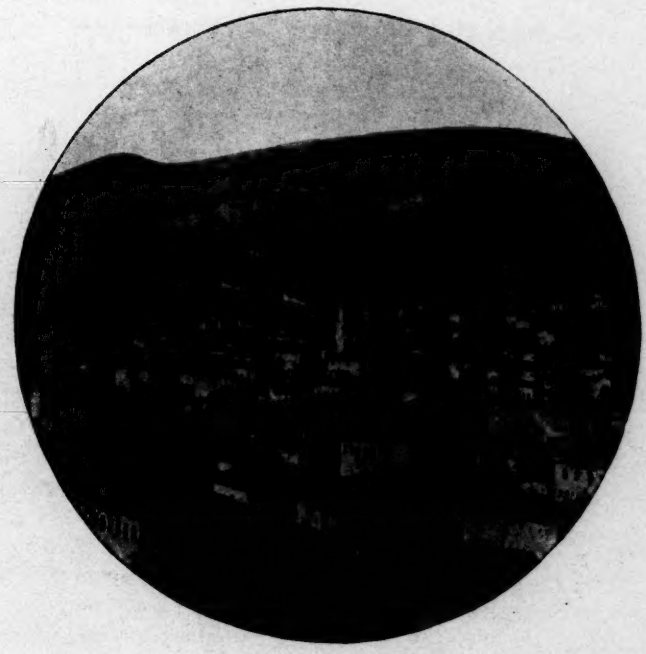


FIG. 9.

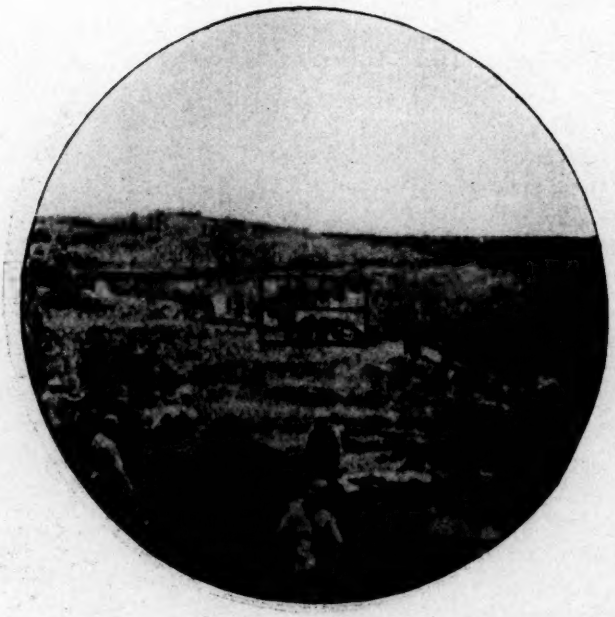


FIG. 10.

Any one with normal eyesight and having equal or nearly equal acuity of vision in both eyes and accustomed to using both eyes can obtain satisfactory results with the stereoscopic range finder after a little practice.

This type of range finder is well adapted for use in the field. Its advantages are:

(*a*) No movable interior parts.

(*b*) Ranges may be obtained at practically the same instant of objects widely differing in range.

(*c*) Ranges may be obtained of objects, such as the smoke from a bursting shell, which are too irregular in form for the erect image coincidence range finder, and of too short duration for the invert range finder.

These range finders have been tried out in the United States Navy but are not suitable for use afloat for this reason.

To obtain accurate results it is necessary to place and hold the image of the target under and close to the line of range points. If the image rises above the range points or falls well below them the range cannot be determined within several hundred yards.

When used on objects suitable in form for the erect image coincidence range finder the stereoscopic type is not as accurate as the coincidence type.

SINGLE-OBSERVER COINCIDENCE RANGE FINDER—INVERTED IMAGE.

The "invert" range finder is a modification of the usual type of coincidence range finder and is especially well adapted for infantry and artillery use ashore. The upper image is inverted; but not reversed right or left. The inverted field occupies only a portion of the upper half of the field, leaving practically the entire field of the instrument clear for purposes of observation.

This method is advantageous in taking observations for ranges on poorly defined or irregularly shaped objects such as smoke clouds, bushes, bodies of troops, etc.

The invert range finder shows a coincidence error by a lack of lateral symmetry which is more easily detected and corrected in objects of irregular outline than an error of alignment. As a consequence, the invert range finder for this class of work has been found to be more accurate than the erect image type.

When the object observed has well defined vertical lines the "invert" range finder may be used as an "erect image" and a coincidence obtained in the usual way.

Figure 10 shows the field of the invert range finder and the appearance of the image.

Range finders of the invert type have the disadvantage that a rotation of the instrument about its longitudinal axis causes the two partial images in the field to move in opposite directions, at right angles to the halving line. When the force of the wind or the vibration of the platform is excessive, it is difficult to keep a small or an indistinct object under observation as the half object is lost to view if it passes the halving line. For this reason, the "invert" type is not a success for use afloat.

THE SINGLE-OBSERVER COINCIDENCE RANGE FINDER—ERECT IMAGE.

This is the type of range finder used exclusively in the U. S. Navy, and, as the name implies, the ranges are obtained by a single observer.

Taking into consideration the ratio of the base length to the ranges usually observed, the accuracy of this type of range finder is remarkable and its accuracy is due in a very large degree to the great exactness with which the eye can distinguish any discontinuity or lack of alignment in the edge of the half images. This point has been previously emphasized on page 18.

It must be understood that the accuracy of observation of the coincidence method also depends to a very considerable degree on the fineness of the separating line. It has been found

in practice that a thick or ragged separating line produces large errors in the ranges.

It is assumed that all are familiar with the principle of the range finder and the method of compensating for the angle α (Fig. 11) by movement of the measuring wedge, K, this movement of the wedge also indicating the range on the range scale.

Consequently all elementary discussion will be omitted.

The following description deals with the ingenious optical system of the Bausch & Lomb (Zeiss) instruments and other features not usually touched upon.

The angle β (Figure 11) is automatically maintained at 90 degrees by keeping the target in the center of the field.

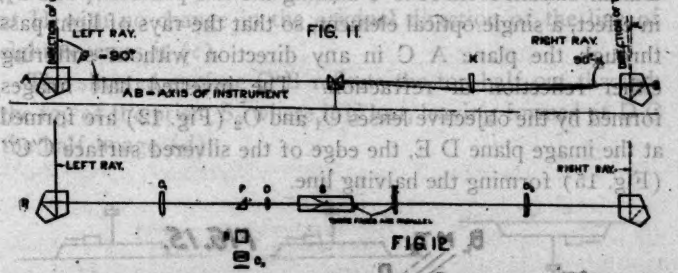


FIG. 11

FIG 12

Prandl or pentaprisms are used as end reflectors in all modern range finders because of the fact that the entering and the emergent rays always make a 90-degree angle regardless of any rotation of the prism about a vertical axis, which might be caused by distortion of the tube of the range finder.

Fig. 12 shows a plan of the essential optical features of the range finder, omitting the self-contained adjuster and other elements not essential to a clear understanding of the construction.

Fig. 13 shows a rear elevation of the left half of the instrument omitting the eye piece lenses O_2 and the reversing prism P.

Fig. 14 shows a side elevation of the rhomboid prism R and the eye piece lenses O_x.

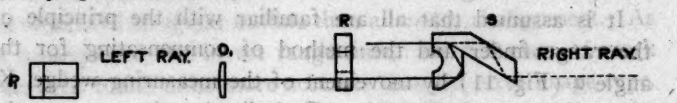
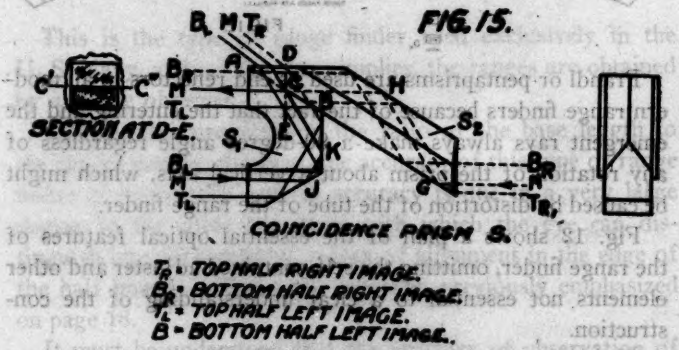


FIG. 13.

FIG. 14.

The coincidence prism S (Fig. 15) is made up of two prisms (S_1 and S_2) in contact at the surface AB. This surface is silvered from C to B (both sides of CB forming reflecting faces to any rays of light striking thereon) and cemented with Damar balsam from A to C making the two prisms S_1 and S_2, in effect, a single optical element, so that the rays of light pass through the plane A C in any direction without suffering either reflection or refraction. The inverted half images formed by the objective lenses O_1 and O_2 (Fig. 12) are formed at the image plane D E, the edge of the silvered surface C′C″ (Fig. 15) forming the halving line.

FIG. 15.


SECTION AT D-E.
COINCIDENCE PRISM S.
T_R = TOP HALF RIGHT IMAGE.
B_R = BOTTOM HALF RIGHT IMAGE.
T_L = TOP HALF LEFT IMAGE.
B = BOTTOM HALF LEFT IMAGE.

The full lines and dotted lines (Fig. 15) show the part played by the coincidence prism in suppressing one-half of

the right image and the other half of the left image, forming a complete image of the remaining half images.

It will be of interest to investigate the effect of each optical element singly upon the target, and for this purpose we will always consider that the eye is looking along the line of sight toward the target.

Assume for a target a ship heading toward the left (Fig. 16). The optical elements of the right half of the instrument, taken in succession up to the point where the half images are joined at D E (Fig. 15), have the following effects (Figs. 12, 13, 14 and 15):

The right penta prism P_2 leaves it unchanged (*a*).

The right objective O_2 inverts and reverses it (*b*).

The right half S_2 (Fig. 15) of the coincidence prism, with two horizontal reflections at G and H and one roof reversal at H with no change in the original direction of the line of sight reverses it (*c*)..

The silvered surface C B reflects the top half out through the top of the prism S_2 where it is lost, leaving formed at D C the half image (*d*).

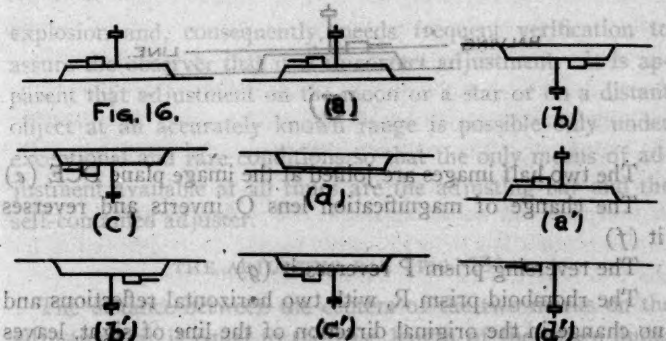


FIG. 16.

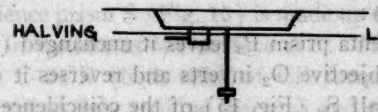
The optical elements of the left half of the instrument taken in succession up to the point where the half images are joined at D E have the following effects:

The left penta prism P_1 leaves it unchanged (a').

The left objective O_1 inverts and reverses it (b').

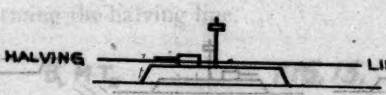
The left half S_1 of the coincidence prism, with three horizontal reflections at J, K and C, and a 180-degree change in the original direction of the line of sight, reverses it (c').

The balsamed surface A C permits the bottom half to pass out through the top of the prism S_2 where it is lost. The silvered surface C B reflects the top half, leaving formed at C E the upper half image (d').



(e)

(f)



(g)

The two half images are joined at the image plane DCE (e)

The change of magnification lens O inverts and reverses it (f)

The reversing prism P reverses it (g)

The rhomboid prism R, with two horizontal reflections and no change in the original direction of the line of sight, leaves it unchanged (g)

The change of magnification lens O in addition to inverting and reversing the image also forms at an image plane within the rhomboid prism a second image of the united half images

seen at DE. This second image is formed near the lower end of the rhomboid prism in the position shown by the heavy line (Fig. 17). The erected half images formed at this point are finally magnified by the eye piece O and this final, magnified virtual image is the image seen by the observer.

METHODS OF COINCIDENCE ADJUSTMENT.

The necessity of a means for coincidence adjustment can be readily understood when it is considered that a range finder, like any other instrument, may be thrown out of adjustment by any unusual shock, such as a near-by shell impact or shell

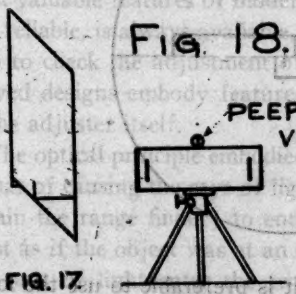


Fig. 18.

FIG. 17.

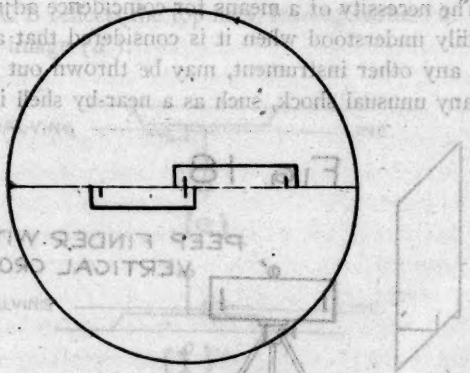
explosion and, consequently, needs frequent verification to assure the observer that it is in correct adjustment. It is apparent that adjustment on the moon or a star or on a distant object at an accurately known range is possible only under exceptional and rare conditions so that the only means of adjustment available at all times are the adjusting bar and the self-contained adjuster.

THE ADJUSTING BAR (FIG. 18).

The distance between the centers of the two marks on the adjusting bar is equal to the base length of the range finder and the adjusting marks must be of the same width. The images of the right and the left hand marks produced by the right and the left sides respectively of the instrument, are observed in the field of the range finder and when the image of

one mark in the upper half field is in coincidence with the image of the other mark in the lower half field the range finder is adjusted for infinity (Fig. 19).

Fig. 19.



In using the adjusting bar it is preferable to use the lower magnification of the range finder; the bar is carefully sighted at the center of the range finder and the adjusting marks brought into the center of the range finder field. These precautions will insure the parallelism of the range finder and the adjusting bar. The adjusting bar should be placed at a sufficient distance from the range finder so that the halving line is sharp and the adjusting marks are in distinct focus. (This distance is not less than 100 yards for the 15 magnification and not less than 150 yards for the 28 magnification.)

Exact experiments by the Carl Zeiss Company in an instrument tunnel proved that the adjusting bar method was accurate provided that the temperature and the atmospheric conditions at the range finder, at the adjusting bar and at all points between them were uniform but that unless these uniform conditions could be obtained this method was unreliable. These

experiments by Zeiss were verified by an extensive series of tests at the Bausch & Lomb factory at Rochester, N. Y.

These uniform conditions are practically impossible to obtain aboard ship and the adjusting bar method should be used only as a last resort as it is fairly certain that its use under non-uniform conditions will introduce an error into the adjustment of the instrument.

THE SELF-CONTAINED ADJUSTER.

The self-contained adjuster is unquestionably one of the most valuable features of modern range finders. It is accurate and reliable, is always available, requires only one or two minutes to check the adjustment of the range finder and the improved designs embody features to compensate for any error in the adjuster itself.

The optical principle embodied in the self-contained adjuster is that of causing the rays of light from a near object (carried within the range finder) to enter the two ends of the instrument as if the object was at an optically infinite distance—i.e., the rays of light enter the two end prisms parallel to each other.

In theory, this principle is simple—from a practical optical and mechanical standpoint it presented many difficulties which were overcome only after extended investigations and experiments. The first self-contained adjuster made is illustrated by Fig. 20.

The vertical line, X_1 being placed in the focal plane of the adjuster objective D_1 is consequently projected to an optically infinite distance. Half of the line X_1 is deflected through 90 degrees by the penta prism, J_1 the other half of the line X_1 passes under J_1 and is deflected through 90 degrees by the penta prism J_2. If this adjuster is so designed that J_1 and J_2 can be brought before the range finder end prisms, our adjuster is constructed in accordance with the desired optical principle and should be reliable at all times. Actual tests with

this adjuster, however, proved that it was not reliable and that the range finder adjusted by this device did not at all times give

FIG. 20.

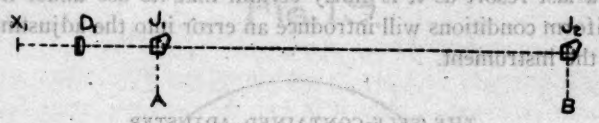


FIG. 21.

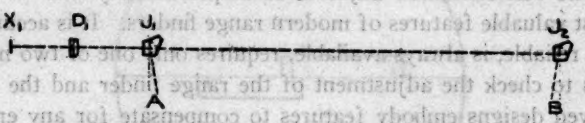
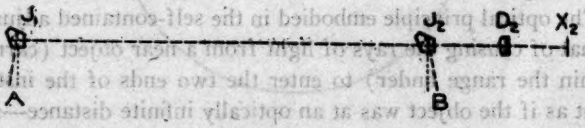


FIG. 22.



correct readings on accurately measured ranges. Careful experiments in the Carl Zeiss laboratories extending over two years developed the fact that it was not absolutely correct to ascribe to a penta prism the property of always producing a constant deviation. It was found that while penta prisms could be so accurately ground that the tolerance of the angles was $\pm$ 6 seconds of arc, the resulting deviation would alter with changes of temperature and, to a lesser extent, even in the course of time. These constant changes are due to the properties of glass which, like all other solids, partakes, to a greater or less extent, of the nature of semi-fluids. These changes cannot be prevented nor predicted; the best that can be done is to retard and minimize them by protecting the prisms as much as possible from changes of temperature and other outside influences.

These changes, while they cannot be prevented, can be perfectly compensated by suitable construction.

It will be apparent from an examination of Fig. 20 that there are three possible cases:

(*a*) The rays A and B are parallel

(*b*) They converge

(*c*) They diverge.

If they are parallel, no compensation is needed.

Assume that A and B converge (Fig. 21).

If, by means of accurate mechanical construction, the two prisms J_1 and J_2 can be rotated through an exact 90-degree angle and a new vertical line X_2 is observed, A and B will now diverge (Fig. 22).

This divergence will exactly equal the previous convergence. The mean between the two successive directions of A and B secures absolute parallelism of the rays of light used for adjusting. This construction is embodied in the improved type of self-contained adjuster. In actual practice, the range finder is set on the vertical adjuster line at one end of the instrument and the position of the index noted on the graduations near α The range finder is then set on the vertical adjuster line at the other end of the instrument and the new position of the

Fig. 23.

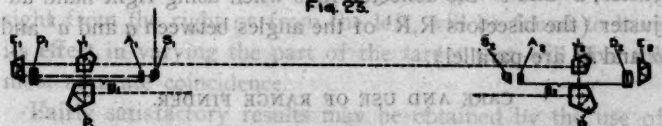
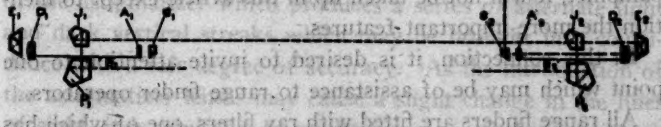


Fig. 24.

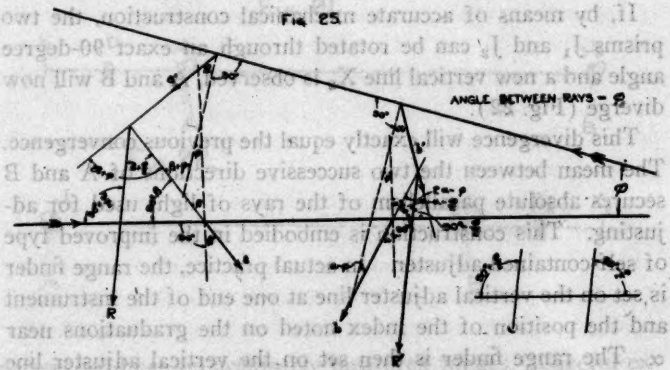


index noted. The index is then set at the mean between the two positions.

Figures 23 and 24 show the position of the optical elements and the path of the rays of light when the left and the right adjuster respectively are being used.

It is essential that the prisms J_1 and J_2 be rotated through an exact 90-degree angle.

Parallelism of the two ends of the adjuster is not necessary to its accuracy, as the effect of parallel rays will always be secured by the 90-degree rotation of the prisms. This is shown geometrically in Fig. 25.



a and *b* are the deflected rays when using the left hand adjuster, a^1 and b^1 the deflected rays when using right hand adjuster (the bisectors R,R^1 of the angles between *a* and a^1 and *b* and b^1 are parallel).

CARE AND USE OF RANGE FINDER.

As this subject is exhaustively discussed in the range finder pamphlet, it will not be taken up in this article except to mention the more important features.

In this connection, it is desired to invite attention to one point which may be of assistance to range finder operators.

All range finders are fitted with ray filters, one of which has sufficient light intercepting qualities to enable the use of the range finder in the direct beam from a searchlight.

In 1909, the "B" runs for destroyers required the destroyers to run directly in the path of a searchlight beam and toward the searchlight and to fire a torpedo at the target when at a given range from the searchlight. During the destroyer practices at Manila that year, the blinding effect of the searchlight beam was entirely overcome and used to great advantage by throwing in the range finder astigmatizer which astigmatized the searchlight beam into a sharp bright line of which an excellent coincidence was obtained.

Experience is the best judge of the part of the target which should be selected to enable the observer to obtain the best results.

Whenever possible, a straight vertical line should be selected. When no vertical line is available, an inclined line may be used but it is of the utmost importance to have the halving adjustment correct as an error of the halving adjustment would introduce an error in the coincidence.

A change in lighting conditions from overcast to bright sunlight or the reverse may increase the difficulty of obtaining an accurate coincidence and will probably necessitate selecting a different side or a different part of the same target to obtain the best results.

Similarly, the position of the sun, whether behind the target or behind the observer or whether shining across the line of sight from the right or from the left, will be found to have its effect in varying the part of the target that will give the most accurate coincidence.

Fairly satisfactory results may be obtained by the use of objects of irregular outlines, such as smoke clouds, by the use of the astigmatizer which produces a series of alternate light and dark vertical streaks which may be brought into coincidence with a fair degree of accuracy. As the introduction of the astigmatizer lenses may cause a slight change in the lines of sight, it is advisable to adjust the range finder for coincidence with the astigmatizer lenses "IN." This can be done very readily by the self-contained adjuster.

When ranging upon very small objects, accurate ranges may sometimes be obtained by changing the halving adjustment so as to "duplicate" the image and then bringing the two images into a vertical line.

The eyepiece must be so adjusted that the halving line is sharp and distinct at the same time that distant objects are in sharp and bright focus. If this condition cannot be obtained, the range finder should be overhauled and adjusted by an expert.

The accuracy of the range obtained depends largely upon the exactness of the coincidence and large errors may be expected in beginners. Range finding is no exception to the general rule that "Accuracy increases with practice." The personal errors of observers decrease as they gain experience. For these reasons permanence of station for observers should be insisted on and every opportunity for practice should be afforded them both on measured and on unmeasured ranges.

Whenever possible the observer should always approach the coincidence from the same side, i.e., with increasing scale readings or decreasing scale readings and, unless lighting conditions or indistinct outline dictate otherwise, the coincidence should always be obtained on the same edge of the target, either the right or the left. The individual observer will obtain better results by so doing than if he used the right or the left edge indiscriminately.

Every effort should be made to keep the observer warm, sheltered from the wind and thoroughly comfortable in all respects. Good results cannot be expected from an observer who is suffering from physical discomfort.

A comparatively low magnification is essential for night use.

Provided that weather conditions are favorable, a higher magnification is greatly superior for day use. When there is a mirage, a more perfect coincidence can be obtained by the low magnification; however, on account of the greater lack of definition of the image when the low magnification is used, at

long ranges, even with a mirage, the average errors are as great with the low magnification as with the high.

When observing in a seaway at ranges in excess of 15,000 yards, it is not to be expected that two consecutive readings by the 12-foot or 20-foot range finder will be nearer each other than 150 yards and the mean of a set of readings, if they can be taken, will give better results than a single reading.

In adjusting range finders on objects at known distances, it is imperative that objects at the greatest possible distance be selected for the following reason:

On page 5 it was shown that with a range finder having a base length of 9 feet the total available angle for measuring all ranges from 500 yards to ∞ was 21 minutes of arc and for measuring all ranges from 1,000 yards to ∞ was 10 minutes of arc.

It is thus readily apparent that divisions on the range scale representing equal increments of range decrease in arithmetical progression with increases in the range—for example—if a range finder graduated from 1,000 yards to ∞ has a range scale 160 centimeters in length it will be divided as follows:

1,000 yards to ∞	160 cm.
1,000 yards to 2,000	80 cm.
2,000 yards to 4,000	40 cm.
4,000 yards to 8,000	20 cm.
8,000 yards to 16,000	10 cm.
16,000 yards to 32,000	5 cm.
etc.	

These tabulated figures show that if a range finder is adjusted on an object at a known distance of 1,000 yards—the distance determined within an error of 1 per cent—this 1 per cent error will result in an introduced error, as follows:

1,000 yards range	10 yards error
2,000 yards range	40 yards error
4,000 yards range	160 yards error
8,000 yards range	640 yards error
16,000 yards range	2,560 yards error

This clearly demonstrates the great importance of adjusting range finders for coincidence on objects at great distances and making the adjustment as accurately as possible.

In checking the adjustment of range finders upon objects at known distances, the following degree of accuracy must be obtained:

With a 9-foot base range finder

The range of an object at	Must be known within
1,000 yards	.5 yards
2,000 yards	1.5 yards
4,000 yards	7 yards
6,000 yards	15 yards

With a 15-foot base range finder

4,000 yards	5 yards
6,000 yards	10 yards
8,000 yards	15 yards

As the accuracy with which a range finder can be adjusted varies directly with the base length, it naturally follows that the longer the base of the range finder the more exactly must we know the range of the objects which we intend to use for adjustment.

The permissible error of .5 yards at 1,000 yards given above for a 9-foot range finder is 1/20 of the error tabulated in the table based on an error of 1 per cent—this permissible error of .5 yards at 1,000 yards would be 128 yards at 16,000 yards which is within the minimum error shown in the table on page 10.

In this connection, it is of interest to refer to a practice that formerly prevailed to some extent. This was the practice of obtaining the range of the target with the range finder, setting the sight bar to the range finder range, firing a trial shot and then moving the scale of the range finder an amount equal to

the spotting correction necessary to bring the shots on the target.

An actual test on the 3-meter Bausch & Lomb range finder showed that applying a 100-yard "correction" at a range of 7,000 yards by moving the range finder scale resulted in a "correction" of 200 yards at 10,000 yards range and in a "correction" of 500 yards at 15,000 yards range.

In range finders fitted with both inside and outside scales there is a chance for an error between the two scales which should be guarded against. The inside scale is directly connected to the measuring wedge, a construction which eliminates any chance for error. The inside and outside scales are connected by a rack and pinions which necessarily introduce some lost motion. In the Bausch & Lomb 3-meter and 12-foot range finders, this lost motion resulted in a difference of from 150 to 300 yards (in different instruments) at 20,000 yards range when moving the scales in the direction opposite to that in which they had been set together. Consequently, in taking ranges it is advisable to move the scales in the same direction as they were moved when setting the scales.

THE PROSPECTIVE UTILIZATION OF VESSEL-TO-SHORE RADIO-COMPASS BEARINGS IN AERIAL AND TRANSOCEANIC NAVIGATION.

By G. W. Littlehales, Member.

The feasibility which radiotelegraph engineers have demonstrated in the measurement of vessel-to-shore bearings by radio-compass promises to have permanent effects upon that branch of navigation in which resort has hitherto been confined to observations of the celestial bodies according to the principles of nautical astronomy. It is a desideratum of importance that means should be furnished to supply the existing deficiency in which observations for finding geographical position at sea are precluded when the firmament is clouded or when the horizon is not visible. In this respect radiotelegraphy has come to the aid of nautical astronomy by affording an observation which will become available for finding geographical position with a degree of serviceability advancing with the improvement of the radio-compass. Indeed, in its present state, the radio-compass is capable of affording practical advantages in aerial navigation, which have not hitherto been secured by other means.

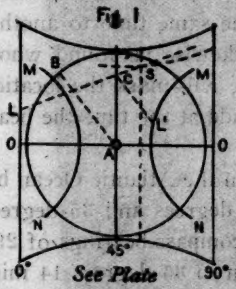
It is the purpose here to describe a method of finding the latitude and longitude in aerial and marine navigation from vessel-to-shore radio-compass bearings, and to follow this presentation with the theory upon which it is founded, and thus to provide that engineers may be supplied with the means of performing the mathematical construction, which is printed in a reduced form in the accompanying plate, upon a scale suited to give results of the requisite accuracy.

The diagram consists of a projection of the parallels of latitude from 63 degrees north to 63 degrees south and of the meridians of longitude throughout an extent of 90 degrees,

upon which there have been centrally superposed, with reference to the intersection of the middle meridian with the equator, a hyperbolic scale of latitudes and also a rim of compass graduations in degrees throughout the circuit of 360 degrees.

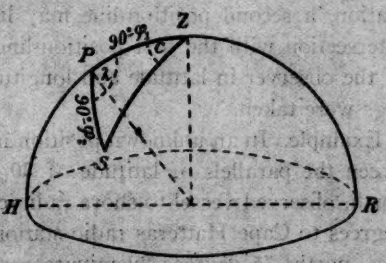
Having measured a bearing from vessel-to-shore by radio-compass, the observer lays down this bearing by means of the compass-rim as in figure 1, AB; then, estimating a latitude as

Fig. 1



See Plate

Fig. 2



nearly as may be to the latitude of the vessel, and marking this estimated latitude upon the hyperbolic scale of latitudes—using the eastern branch when the bearing is to the westward and the western branch when the bearing is to the eastward—the line A B is shifted parallel to itself so as to pass through the latitude division, L′, as marked on the hyperbolic scale, and the point C where the shifted line L′C intersects the middle meridian is thus determined. Finally a line is drawn from C to a point L on the left-hand border scale of latitude marking on that scale the same estimated latitude as was before marked on L′ on the hyperbolic scale, and the meridian passing through the point, S, where this line LC or its prolongation intersects the curve of latitude corresponding to the known latitude of the station to which the vessel-to-shore bearing is taken will indicate by its number the corresponding longitude of the observer with reference to the known longitude of the station.

It will be evident that the longitude so deduced will be the true longitude of the vessel only in case the latitude which has been chosen is the true latitude, so that if another value of the latitude is chosen and a second value of the longitude is deduced from the original vessel-to-shore bearing, following the same steps as before, a position-line may be drawn through the two points, thus located by the two chosen latitudes and their corresponding longitudes, at some point of which the observer must be located. And if a second vessel-to-shore radio-compass bearing be taken at the same time to another station, a second position-line may likewise be found whose intersection with the first position-line will mark the location of the observer in latitude and longitude at the time the bearings were taken.

Example. In an unknown position in the Atlantic Ocean between the parallels of latitude of 30 degrees and 35 degrees north, observed vessel-to-shore radio-compass bearings of 290 degrees to Cape Hatteras radio-station in 35 degrees 14 minutes, north, 75 degrees 32 minutes, west, and 329 degrees to Cape Cod radio-station in 42 degrees 3 minutes, north, 70 degrees 5 minutes, west. Find the latitude and longitude of the observer.

FROM THE DIAGRAM.

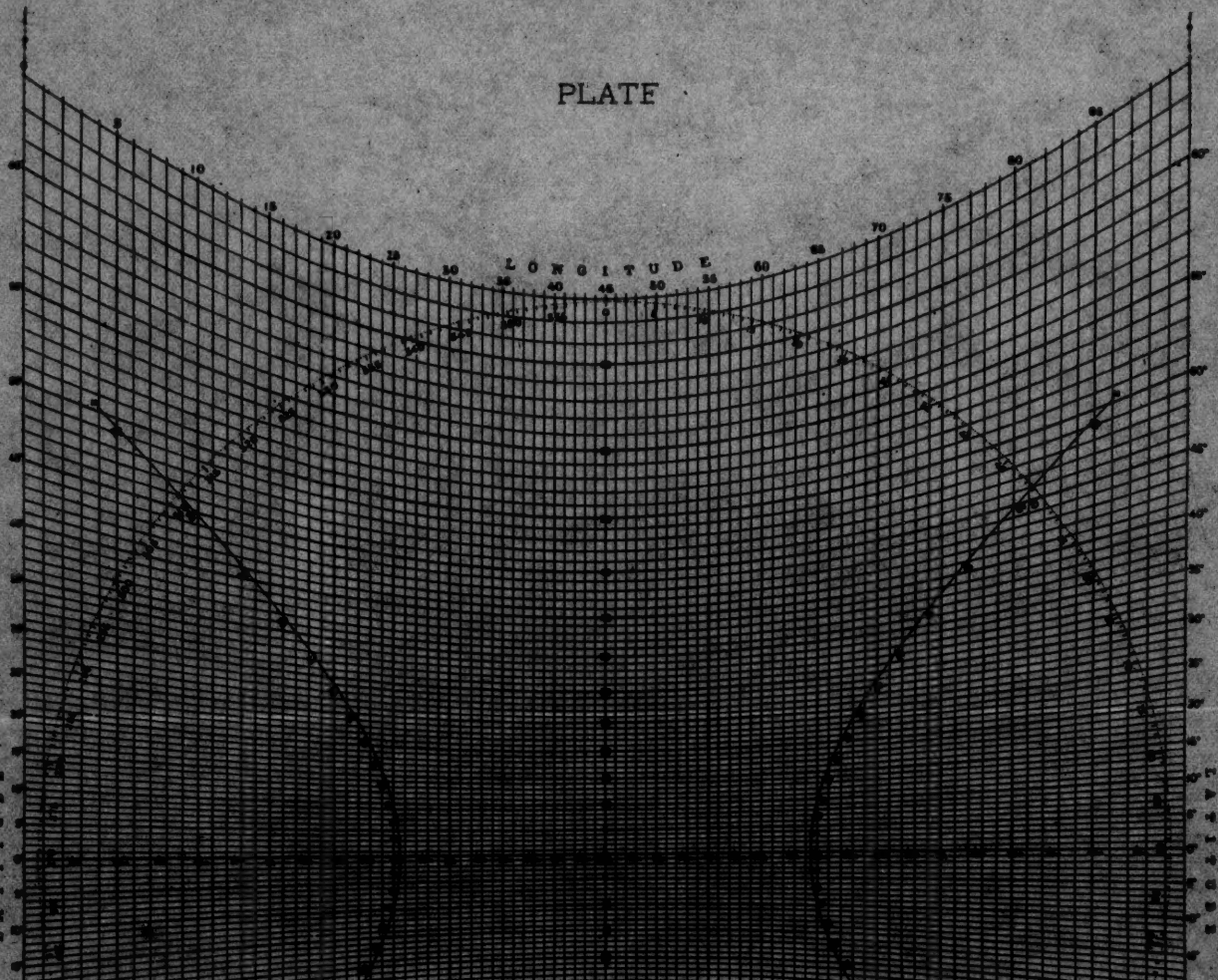
For the first bearing.

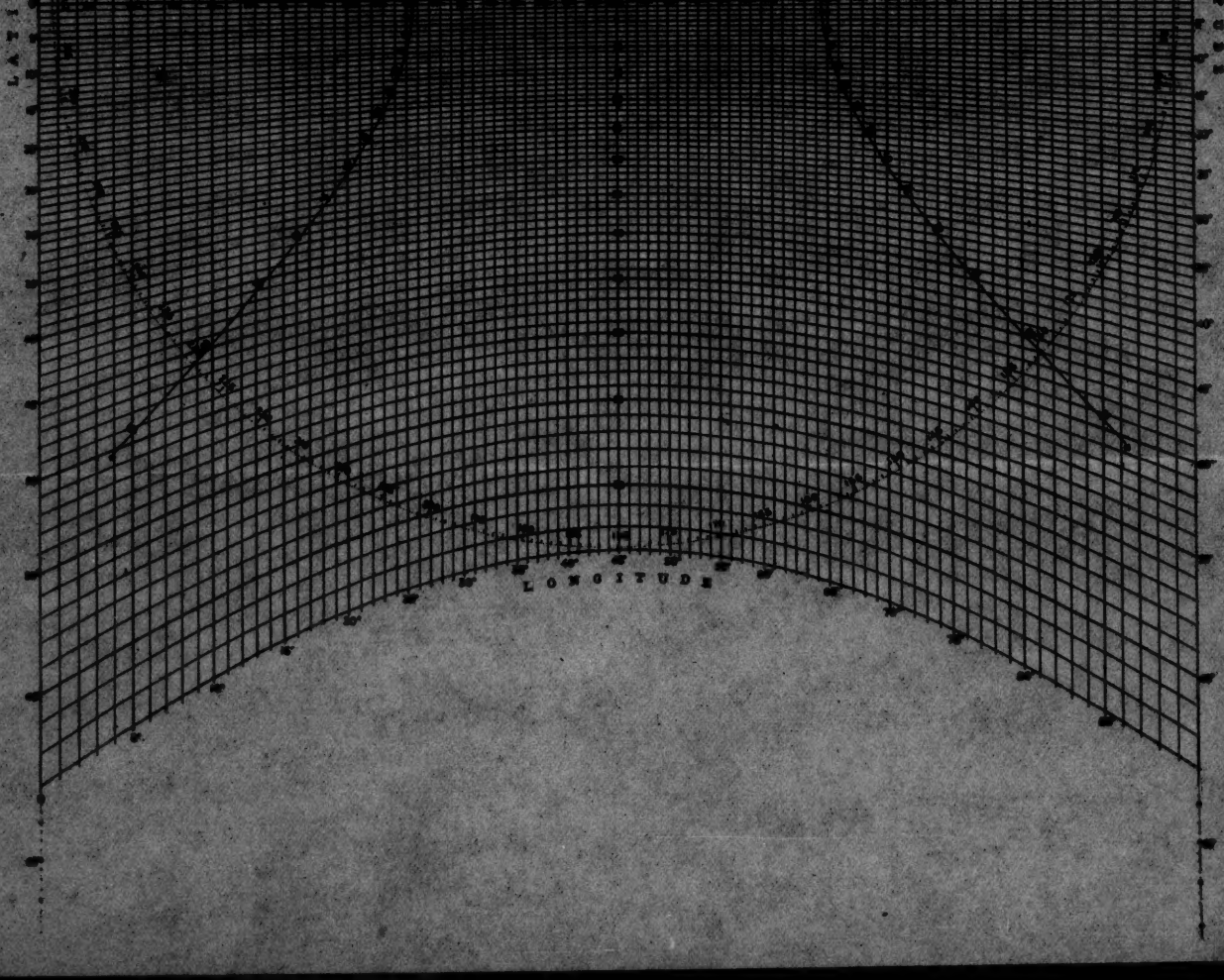
Assumed Lat. *Degrees*	Corresponding Longitude from Hatteras *Degrees*	Longitude from Greenwich *Degrees*
31	$19\frac{1}{2}$	56
32	$13\frac{1}{2}$	62
33	$8\frac{1}{2}$	67

For the second bearing.

Assumed Lat. *Degrees*	Corresponding Longitude from Cape Cod *Degrees*	Longitude from Greenwich *Degrees*
31	9	61
32	$8\frac{2}{10}$	$62\frac{2}{3}$
33	$7\frac{1}{3}$	$61\frac{8}{10}$

PLATE




LONGITUDE

The lines drawn through these positions upon a chart, show by their intersection the observer's geographical position to be in latitude 31 degrees 8-10 north and in longitude 61 degrees 1-3 west.

If a shore-to-vessel bearing is received by the vessel at the same time as the vessel-to-shore bearing is measured, the foregoing process of finding the geographical position becomes yet more simple, since it is then unnecessary to find two position-lines or to solve for successive assumed latitudes, because the latitude of the vessel may be found by the following proportion:

cos.Lat.vessel : sin.shore-to-vessel bearing : :
cos.Lat.radio-station : sin. vessel-to-shore bearing.

This proportion is already computed in Table V of Hydrographic Office publication No. 200, entitled Altitude, Azimuth, and Line of Position, from which the required latitude of the vessel may be found, especially if the tabulation is carried out in somewhat greater detail, by considering the arguments of the table to be renamed as follows:

For Hour Angle substitute Shore-to-Vessel bearing.
For Declination substitute Latitude of shore station.
For Azimuth substitute Vessel-to-Shore bearing.
For Altitude substitute Latitude of vessel.

As will appear in the sequel, the necessary relations for performing this solution for geographical position also exist in the Time Azimuth Tables, in which are tabulated the true bearing of celestial bodies for stated values of the latitude of the observer and the declination and hour-angle of the observed celestial body; and, although in the present state of such tables the intervals between the arguments are such as to give rise to the necessity for interpolation, yet they are entitled to mention, since, by opening the tables at the latitude chosen by estimation and finding the measured vessel-to-shore bearing in that column of tabulated values of the azimuth which has at its head a value of the declination equal to the latitude of

the shore station to which the radio-compass measurement is taken, the longitude from the shore station will be found in the hour-angle column opposite to the given bearing.

Passing now to the theoretical considerations which underlie the construction employed to produce the results which have been described, it is only necessary to recognize that the vessel-to-shore bearing is identical with the initial course along the great-circle track from the vessel to the shore station, and so to find a basis for analysis in the formula for finding the azimuth or the course in great circle sailing. The problem of finding the initial course on a great circle track passing between two given geographical positions may be stated thus: Given two sides and their included angle in a spherical triangle, to find the angle opposite to a known side. In Figure 2, let the arc ZS represent a great circle track joining the point of departure Z with the point of destination S, and let P represent the position of the elevated pole of the earth, then PZ and PS will represent arcs of the meridians of longitude passing through Z and S respectively, the angle ZPS will represent λ, the difference of longitude between Z and S, and if φ_1 is the latitude of Z and φ_2 the latitude of S, the length of the sides PZ and PS of the spherical triangle PZS will be 90 degrees $-\varphi_1$, and 90 degrees $-\varphi_2$ respectively.

From the fundamental formulæ of spherical trigonometry, the following relation subsists:

$$\sin(90^\circ - \varphi_1)\cot(90^\circ - \varphi_2) = \cot C \sin\lambda + \cos(90^\circ - \varphi_1)\cos\lambda \quad (1)$$

$$\text{or } \cos\varphi_1 \tan\varphi_2 = \cot C \sin\lambda + \sin\varphi_1 \cos\lambda \quad (2)$$

$$\text{whence } \cot C = \frac{\cos\varphi_1 \tan\varphi_2 - \sin\varphi_1 \cos\lambda}{\sin\lambda} \quad (3)$$

Dividing both terms of the fraction of the second member of equation (3) by $\cos\varphi_1$,

$$\cot C = \frac{\tan\varphi_2 - \tan\varphi_1 \cos\lambda}{\sec\varphi_1 \sin\lambda} \quad (4)$$

$$\text{or} \quad \cot C = \frac{\tan\varphi_2 - \tan\varphi_1 \cos\lambda}{\sec\varphi_1 \sin\lambda - 0}. \quad (5)$$

Putting

$$\begin{aligned} y &= \tan \varphi_1 \cos \lambda \\ y' &= \tan \varphi_2 \\ x &= \sec \varphi_1 \sin \lambda \\ x' &= 0 \end{aligned} \qquad (6)$$

equation (5) becomes

$$\cot C = -\frac{y - y'}{x - 0}. \qquad (7)$$

Therefore C, the vessel-to-shore- bearing, is the angle made with the axis of Y by a straight line joining the points (x, y) and (x', y').

From equation (6),

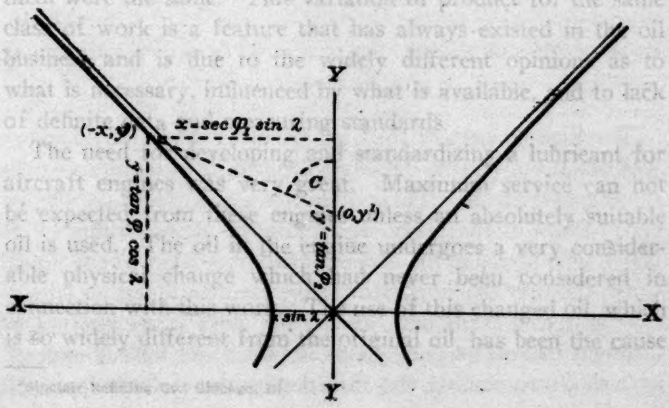
$$\frac{x}{\sin \lambda} = \sec \varphi_1 \text{ and } \frac{y}{\cos \lambda} = \tan \varphi_1 .$$

or

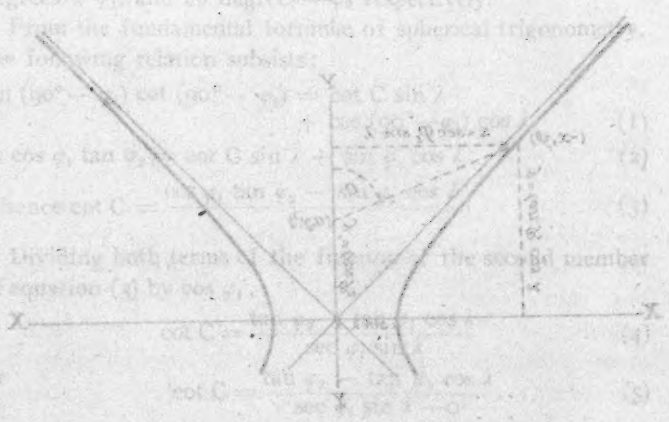
$$\frac{x^2}{\sin^2 \lambda} - \frac{y^2}{\cos^2 \lambda} = \sec^2 \varphi_1 - \tan^2 \varphi_1 = 1$$

which is the equation to a hyperbola whose semi-minor and semi-major axes are sin λ and cos λ, respectively. Therefore the point (x, y) will always be found upon the arc of a hyperbola, figure 3, upon whose major axis the corresponding point

Fig. 3



(o, y^1) is found with reference to a scale of tangents representing $y^1 = \tan \varphi_2$. In the construction of the hyperbola in the accompanying plate, λ was taken to be equal to 45 degrees in order that provision might be made always to find the latitude of a point 45 degrees of longitude from the vessel toward shore station on any given vessel-to-shore bearing, this being the extent of longitude from the middle meridian to the bounding meridian in the gnomonic projection with point of tangency on the equator, which forms the system of parallels and meridians upon which the diagram is based.



LIBERTY AERO OIL.

By William F. Parish, Associate,*
CHIEF, OIL AND LUBRICATION BRANCH, AIR SERVICE, U. S. ARMY.
REPORT TO EQUIPMENT DIVISION, SPECIFICATION SECTION, SIGNAL CORPS.

INTRODUCTION.

The purpose of this work was to develop a suitable mineral lubricating oil for use in the aeronautic engines of the fixed or stationary cylinder type.

In order to take full advantage of the development work already done by the different oil refiners, only oils that had been fully worked out and found suitable for this type of engine were tried out on the engines at the testing laboratory.

Quite naturally, as is generally the case with every product manufactured by widely different methods and from different raw materials, the oils already developed and put in use at the various fields and various manufacturing plants varied through the widest range, even though the demands made upon them were the same. This variation of product for the same class of work is a feature that has always existed in the oil business and is due to the widely different opinions as to what is necessary, influenced by what is available, and to lack of definite data and measuring standards.

The need for developing and standardizing a lubricant for aircraft engines was very great. Maximum service can not be expected from these engines unless an absolutely suitable oil is used. The oil in the engine undergoes a very considerable physical change which had never been considered in connection with this work. The use of this changed oil, which is so widely different from the original oil, has been the cause

*Sinclair Refining Co., Chicago, Ill.

of many engine failures, and much of the difficulty in operation and maintenance can be traced to its use. Military necessity requires that aviation engines be kept at a high degree of efficiency; that they be ready at all times to perform their duty, and that they be lubricated by the oil that has continuously the greatest factor of safety. Many other features have developed as a result of this present work, which will have a direct bearing on the operation of these engines. The questions of period of renewal of the oil, of effect of the gasoline upon the lubricant, of the temperature of the engine and of the oil in starting the engines, and the further question of reclamation of used oil, storage and all around handling of the lubrication and fuel problems in the field have been the direct result of this work. These items will all be covered in separate reports.

The result of the entire work will be that through the specification, which is embodied in this report and which is made up as a result of consideration of all the factors that have been developed, and through the entire system of handling the oil and fuel which comes under this general subject, we shall be able to secure the maximum life and performance of our engines with a minimum amount of lubricant and of cost and time in handling the engines when out of service.

CO-OPERATION BETWEEN THE NAVY DEPARTMENT AND SIGNAL CORPS.

The Signal Corps of the U. S. Army, at the time this work was taken up, had no facilities to make as elaborate tests as those contemplated. The matter was explained to the Engineer-in-Chief of the Navy, Rear Admiral R. S. Griffin, U. S. Navy, who placed at the disposal of the engineers of the Signal Corps the very fine apparatus at the aeronautic testing laboratory at the Washington Navy Yard, with many engines of different makes, machine shops, supplies and trained experts, as well as furnishing the facilities of the well equipped oil

testing laboratories at the Naval Engineering Experiment Station at Annapolis. It would have been impossible to have accomplished this work without this very fine co-operation and assistance.

The laboratories at the Bureau of Standards were also used for special readings on oils tested, and special tests were also made in the laboratory of the Tide Water Oil Company and in the chemical laboratories of the Washington Navy Yard. The laboratories of the Bureau of Mines, the Galena-Signal Oil Company, Franklin, Pa., the Standard Oil Company of New York and the Texas Company of New York, were also called upon for men and instruments, and all the assistance asked for was promptly furnished.

CO-OPERATION BETWEEN THE SIGNAL CORPS AND THE OIL INDUSTRY.

Before and during the entire progress of the test the experts connected with all oil refining and oil sales companies were called upon for ideas and advice in an endeavor to make this test as comprehensive as possible. Due to the speed with which the work was done, it was quite impossible to include all the ideas of the late-comers, and close study of the log sheets, especially the figures showing determinations of ash and gasoline, will show that these observations were not made during the first part of the tests; and where samples were not available for checking back, the record is necessarily incomplete. Further, as is true in other lines of business, the development and scientific testing work carried on in the oil business is not published but is kept as an asset of the operating company. Many features had to be considered in developing this oil, and it can be said with credit to the oil industry that all of their carefully compiled records were placed at our disposal freely and without controversy. At the same time, the entire industry offered their plants, products, laboratories and personnel, and stated that they would do anything that was asked of them in connection with the development work and

in connection with supplies that would have to be furnished after the development work was completed.

TESTING ORGANIZATION (SHEET NO. 2).

In work of this kind it is necessary that all branches of the organization operate at the same speed. Errors are bound to creep in and variations are constantly in evidence, but when the practical testing work progresses with the chemical laboratories only one day behind, it is possible to closely check and guide the development. Two instances of the close co-operation of the work will illustrate:

In examining one engine it was found that considerable wear had taken place, due to the unsuitability of the oil in use, and it was necessary to order new rings before the engine could be used for further tests. Within a few hours after receiving the above report, the Chief of the laboratory at Annapolis called up and stated they had found an excessive amount of iron in the used oil samples from the tests of the day before, thus checking the wear of the piston rings reported upon by the officer in charge of the test.

Another instance was in the work on reclaimed oil, a quite new subject. The laboratory Chief at Annapolis telephoned that they had just examined the reclaimed oils which, after use, were taken from the engine the day before, and it was their opinion that the test engine should run much better with a reclaimed oil than it would run with the same oil when it was new. Within a half hour, the officer in charge of the test called up and reported that the test engine had been examined, after opening up for photographing, and it was in very much better condition from use of the reclaimed oil as far as cleanliness and general lubrication were concerned, than it was from use of the same oil when new.

VARYING FACTORS IN THE WORK.

In testing work on a large scale and under high speed conditions, inconsistencies are bound to show in the record. The-

oretically, certain effects should follow certain causes; practically, on this kind of testing work, some variable factor operates at times and the curve does not always act as it should. To compensate for these variables and average all conditions, it is necessary to make many observations and over a considerable period of time and to use the same operators and instruments on the same stations; and everything possible that good judgment could dictate was done on this work.

The variable factor due to carburetion has affected results more than any other one item. Carburetion, of course, is due to a number of features not readily controlled. The result of variation in carburetion is a difference in the amount of gasoline used and a like difference in the amount escaping past the piston rings during the compression stroke, and contaminating the lubricating oil. Power of the engine and temperature of the cylinder are likewise affected. It is impossible in a test of this nature, operating over a period necessary to complete the work, to absolutely control this feature of carburetion so as to eliminate any variation produced by this cause; and in the general discussion of the results of these tests, it will be found necessary to call attention to this fact.

Instruments and meters, and parts not easily obtainable, go out of commission and repairs on new equipment can not be secured in time to finish the work—and this explains the lack of some information on certain engines upon water measurements and oil temperature measurements. Variations are also bound to exist in laboratory work, and a certain amount of latitude must always be allowed, especially so in this case where samples of all oils were sent to the laboratories under number only, and in the case of new oils for each test, where the samples were necessarily duplicated, several similar samples were reported upon at various times without there being any indication to the laboratory men that the oils were the same. There is also a further feature, which will be later worked out—that is—in oils of the nature required for these

engines there is always apt to be some slight difference due to imperfect combining of light and heavy products, and the variation which will be noted in the laboratory readings on the same oil might be due to slight variation in the oil itself, even though the samples came from the same package.

While these engines were on the testing block, they were operated in the open air, and the results will more nearly approximate those of actual use than would be the case had all of the variables that so much affect the work, such as temperature and condition of the air and the carburetor adjustment necessary to compensate for these variables, been controlled and held constant. The rules that necessarily follow consideration of the data accumulated during this test are those that will apply to actual conditions under which the engines will have to operate.

PRESENT IDEAS IN REGARD TO LUBRICATING OIL.

There are certain things that the technical and practical oil man—and even the layman—has always believed and taught, which will, of necessity, have to be discussed at this time. Without going into the subject fully, it can be stated that, with the very best of intentions, there have always been strong advocates of both high and low gravity oils, of high and low flash point, of high and low viscosity. Many of the faithful followers of these creeds have not been able to investigate the matter themselves, and the makers of the creeds have been governed almost entirely by commercial considerations; and in this, the oil business is not dissimilar from other branches of industry. It is just as well to state briefly the various points that have a bearing on this subject, with the conclusions that are possible after a careful study of the results of this test.

GRAVITY.

The gravity of an oil indicates the source of the crude from which the oil was made. High specific gravity shows that the oil originated from an asphaltic or naphthene base crude; low

specific gravity indicates, generally, that the oil was made from a paraffine base crude; and a medium gravity indicates, generally, that the oil was made from a mid-continental crude or that it was made by a mixture of the high and low gravity oils. The tests on these engines have shown that while the gravity of the oils, as a rule, does not get out of its original classification, yet it varies considerably from hour to hour as the oil undergoes changes in the engine, these changes being due entirely to result of the mixture of gasoline, with a possible slight change that takes place in the oil itself from decomposition. Gravity, therefore, besides being valuable as a method of determining the source of the original crude, has a value in checking and determining the amount of gasoline or fuel that the oil has taken up during its period of operation in the engine.

FLASH AND FIRE.

The flash point of an oil is the temperature at which it gives off a vapor that will ignite and flash upon being lighted. The fire point is the somewhat higher temperature at which the same oil will emit sufficient vapor to burn steadily upon being lighted. This particular feature of an oil has been made a great deal of by all oil men and even those technically inclined outside of the oil business, high flash and fire point being considered a very valuable attribute of an oil—probably for the reason that one would naturally suppose that this characteristic represented, to a degree, the heat-resisting qualities, and when the oil was to be used under high temperature conditions, it was naturally supposed that this feature would have considerable weight.

High or low flash and fire point and low or high specific gravity are due to basic characteristics of the original crude. Those who have had the naturally high flash point oils to sell are loud in their praise of this feature; and those who work with oils not naturally possessing this characteristic, outside of

a very few, are apologetic when the subject is brought up. Naturally, consideration has only been given to the finished oils as manufactured and as they appear in the original packages or in sample bottles, or upon the records as represented by chemical tests on the new oils; no thought has been given to the flash and fire that the oil would have when in the crank-case or lubricating system of an internal combustion engine. As a matter of fact, as is clearly demonstrated by the records of this test, the flash point of any oil in operation is practically the flash point of the heavy end of such gasoline as is absorbed by the lubricant, and, as will be dealt with later, the power of absorption varies with different oils. The fire point of an used oil varies from the original to a less extent than the flash point, because at the high temperature at which the fire point develops all gasoline and most heavy ends have been driven off.

POUR TEST OR COLD TEST.

The pour test of an oil is that temperature at which the oil will congeal and not move in a four-ounce bottle. In the case of paraffine lubricants, due to the wax content of such oils, the pour test is relatively high. In the case of the asphaltic or naphthene base lubricants, due to the absence of wax, the cold or pour test is low, these features being entirely due to the nature of the oil—considering only the class of oils necessary for this particular aero engine work. An intermediate cold test oil can be secured by mixing the high and low cold test oils.

The question of the cold test of the oil does not possess value for this work if the oil is handled properly in the fields in accordance with systems that have been designed for the purpose of heating the engines before they are placed in operation; though low cold test is, as a rule, a valuable adjunct to an oil as it allows action under low temperatures when oil not possessing this characteristic will be set and thereby retard the first attempts to start the engine when everything is cold. The solution of the problem of starting our engines

when they are cold will not be met by any low cold test feature possessed by the oil itself, but will be secured entirely by the mechanical handling of the oil, and this will be covered in supplementary report under the heading "Oil Storage and Reclamation System and Report on Engine Heaters."

The cold test of an oil in the engine undergoes a very remarkable transformation, due possibly to the absorption of gasoline or the heavy ends from the gasoline, and in the case of one or two oils used on this test, the change was probably due to separation of the basic oils used for making the finished products.

VISCOSITY.

Viscosity is a term used to designate the fluidity of an oil. This determination is made on a Saybolt Universal Viscosimeter where sixty cubic centimeters of oil at a fixed temperature flow through a standard orifice and the time of flow is taken in seconds. The time in seconds is then used as a standard of measurement. All oil possesses fluidity in practically the same degree with this exception—that at low temperatures approaching the pour test of the oil, the viscosity of a naphthene base lubricant is very high as compared to the viscosity of paraffine base lubricants of the same general body at ordinary temperatures. At working temperatures above 130 degrees F. and from that on to 250 degrees F., there is but slight difference in the viscosity curves of paraffine and naphthene base lubricants.

There is no such condition as "breaking down" of either the asphaltic base or paraffine base lubricant when subjected to heat as shown by the viscosity curves. Oils from both crudes may have the same viscosity or body at 250 degrees F., or at working temperatures and yet vary in their viscosity at lower temperatures, but this is not an indication of breaking down in any sense of the word: it simply means that at lower temperatures approaching the cold test point of the oil, the paraffine lubricant will be more fluid than the asphaltic base

lubricant until the pour point of the oil is reached when, in the case of a paraffine lubricant, due to its ceasing to flow, there will be no further viscosity determination possible, while at still lower temperatures there will be viscosity determinations possible with an asphaltic base oil. The above relates entirely to determination of viscosity in the laboratory and upon new oils.

An oil undergoes a very great change in viscosity while it is working in the engine and this change is due entirely to the leakage of the gas by the piston rings, and, after condensation, to the absorption of its heavy portion by the lubricant and possibly to light products thrown off through a slight process of decomposition. The power of absorption possessed by the lubricant governs the lowering of the viscosity. The oil that will absorb gasoline the least will be reduced in viscosity the least through this cause, and such an oil will more nearly maintain its original body or viscosity while working in the engine than will an oil that has a greater tendency to absorb gasoline. In every case, as indicated by the charts, every oil has been reduced in viscosity to a remarkable extent during the first hour of operation. Many of the oils slightly recover during the balance of the test, while others continue to absorb the gasoline and to become further reduced in body. The viscosity as taken at 212 degrees F., shows but a slight variation due to gasoline absorption as at this temperature the oil in the instrument has given up all of the gasoline and practically all of the heavy ends that are responsible for the considerable effect at lower temperatures. The viscosities on the new and used oils at 300 degrees F. are practically identical within the range of error of observation. By consideration of this principle of gasoline absorption it will be evident that the present method of selecting a lubricant when new and not considering the viscosity of the oil in the engine is radically wrong and probably, to an extent, accounts for many of the engine failures.

CARBON AND SEDIMENT.

The carbon residue determination, as made at the Annapolis laboratory was by the Conradson method which consisted practically of distilling a small portion of the test oil until a residue was left, and then comparing the weight of the residue to the weight of the original sample.

The carbon test by the Waters method, as used at the Bureau of Standards, is the difference between the amounts of the sample insoluble in petroleum ether before and after oven treatment—this difference being reported as "carbonization."

Volume and Weight Tests.—The sediment contained in a sample taken from the circulating system at the end of five hours was precipitated and an indication secured as to the percentage by volume. (This observation, however, was not possible in all readings.) The sediment was then removed from the oil and weighed in order to secure the percentage by weight. This last indication can be taken as a standard in judging the amount of carbonization that takes place in an oil and that is carried with the oil through the circulating system.

There was no value reported by the Waters test on a number of samples of new oil. Where values were given, a chart shows that the relation between this test on new and used oil was uniform. There is also a fixed relation between new and used oil readings by the Conradson method. By both methods, the readings on the new oils have lower values than the readings on the used oils. In the following comparisons the readings on the oil taken from the engine at the end of five hours will be used; the figures are given on sheet No. 28.

The chart lines representing the carbonization value by the Waters method and the line showing the percentage of sediment by weight are very closely related, especially when comparing the low specific gravity oils. The carbonization value, by the Waters method, for the high specific gravity oils is greater than that given the low specific gravity oils as compared

to the sediment by weight; that is, the value by the Waters method seems to be magnified for the high specific gravity oils. The gravity of the oil is very well indicated by the Waters test, there being a wide range between the two general classifications of crudes. The Conradson method checks to an extent with the sediment by weight measurements of the low specific gravity oils but does not check with this reading of the high specific gravity oils.

Oil J, which gave the cleanest engines on the test, has the lowest Conradson carbon value for each set of tests and this oil is reported with a high value by the Waters method. The action of this oil in the engine was that it formed a great amount of carbon which came out the exhaust in a remarkable manner, but this carbon was not of a nature that allowed it to stick and accumulate inside the engine, and no more of this carbon seemed to go back into the circulating oil than with a number of other oils.

The oils that gave the greatest amount of carbon in the engine were those that showed the largest carbon content by the Conradson method and the lowest value by the Waters method, with the possible exception of oil B, the lightest oil tested; this oil, for the test on the Hall-Scott engine, showed an excessive consumption due to its light body, and the carbon left in the engine was undoubtedly from that cause.

With oils of the same classification as to crude, the carbon content, Conradson, is directly related to the viscosity of the oil at 212 degrees F., and the carbon content by the Waters method is directly opposed to the viscosity at 212 degrees F. (see chart No. 1).

ACIDITY.

The acid number is the number of mg. of KoH taken to neutralize the free acids in one gram of oil. The acidity of all oils increases during operation in a quite consistent manner. If it were not for the fact that the oil having the highest acid number of any of those tested operated in a most successful

manner, leaving the engine cleaner than it had been left with any other oil, there would be some interesting information that could be deduced from this observation. As long as low acid number does not seem to indicate any desirable quality in an oil and on the basis of the perfect operation of the one oil having a high acid value, the conclusion was reached that this determination is of little practical value for the work in hand. The development of the reclamation system, where the oil was recovered by a water and soda ash treatment made the use of oil J impossible. It was then found that oils of high acid value could not be reclaimed.

DEMULSIBILITY.

According to Technologic paper N. 86, published by the Bureau of Standards, on page 31 appears the following:

"Transformer oils, as a rule, have a demulsibility of 1,200 * * * an additional proof * * * that high demulsibility is an indication of great purity."

As 1,200 represents an oil of great purity, zero at the other end of the scale is taken to represent an unsuitable lubricant. The demulsibility of the oil on test No. 5 showed a value of 109; this oil was not at all satisfactory on account of the excessive consumption and carbon. Four other oils were reported upon with lower numerical values; the thirty-one other tests have been reported upon as zero or without any value whatever. From the results of this series of tests, it can be said that the test for Demulsibility has no value whatever for oils necessary for this service.

GASOLINE ABSORPTION.

During the compression stroke, when the charge of gas is being compressed in the cylinder at pressures as high as 120 pounds per square inch, there is a leakage past the rings, and this gas, upon reaching the crank case, is condensed, the heavy ends of the gasoline being absorbed by the lubricant. Should

the lubricant be working at constant low temperatures, it would hold a greater proportion of gasoline heavy ends than would be the case were the oil working at a temperature that would drive off most of this light product. This is proven by the results of this test where the engine that operated at the highest temperature allowed the same oil to operate at higher flash and higher viscosity after the same length of time than was the case in another engine where the oil was much colder (see tests Nos. 7 and 9). It is also to be noted that different oils possess the virtue of holding or not holding these heavy ends in different degrees, as can be noted by comparing the drop in flash of the low specific gravity oil on test No. 15 with the very much less drop of the high specific gravity oil on test No. 19, the readings being as follows:

Test No. 15 Flash when new, 440 degrees F.; after 5 hours, 130 degrees F.

Test No. 19 Flash when new, 390 degrees F.; after 5 hours, 200 degrees F.

This feature checks through the test and shows that, as a rule, the oils that are of high specific gravity seem to possess the power of not absorbing the heavy ends of the escaped gasoline, though two low specific gravity oils also seem to possess this characteristic when working in some of the engines. It may be that this characteristic in a heavy lubricating oil is not entirely a matter that is governed by the crude, as would seem to be strongly indicated; it may be a characteristic that has to do with the manufacture of the oil.

Dr. J. B. Garner of the Mellon Institute of Industrial Research has conducted experiments that have not been released for publication, which indicate that the nature of the crude from which the oil is made has a great deal to do with the absorbent quality, and that there is no relation between this quality and viscosity. In a signed statement, which is to be found in the original documents and records of this work, he makes the following statement:

"1. The absorbent quality of the asphaltum base distillates, having the same distillation range, is always less than that of the paraffine base distillates.

"2. California Mineral Seal, the best asphaltum base distillate, has an absorbent quality of only 71.9 per cent of that possessed by Eastern Mineral Seal, the best paraffine base absorbent distillate."

The large number of carefully checked experiments that led to this conclusion were made by the Mellon Institute for the purpose of finding the oil that would absorb gasoline to the greatest extent. From a close consideration of all the facts and charts resulting from the present work, the oil for the lubrication of the aircraft engine should be an oil that will absorb gasoline to the least extent as such an oil will undergo the slightest change in the engine.

PRIMING.

The present practice in starting these engines is to prime freely with gasoline, especially on cold mornings. At some fields lubricating oil is mixed with gasoline in order to ease the engine when it finally does start. Cases are on record where priming was resorted to to such an extent that the gasoline, which had run down into the crank case, exploded and wrecked the engine. Other cases are on record where, due to priming and washing the lubricant from the walls of the cylinders, damage was done immediately when the engine was started, before the lubricant could get between the surfaces. There is no question but that heating an engine, if only by putting steam through the water circulating system, will allow an easy start and a quick getaway without priming. The reason is that the oil is made more fluid on account of the heating and therefore circulates more freely. It seems wise to establish a complete heating system if only to overcome the necessity for priming with the consequent danger and damage to the engine. From a military point of view, the quick getaway

should warrant any system that would make the engines immediately available when they are required.

CLEARANCES.

The clearances that are allowed for bearings lubricated by means of a forced feed system must be considered in the light of a check or throttle valve to the outlet of the system. Close clearances have the effect of checking the flow of oil by reducing the outlet; wide clearances allow of the free passage of the lubricant. Close clearances are always accompanied by high pump pressure as compared to wide clearances with the same lubricant; therefore, with the same lubricant, higher pump pressure can be secured by reducing the clearances. With the reduction in clearance there is a reduction in the amount of oil that flows through the bearing. With the same clearance it is necessary to decrease the body of the lubricant to increase the flow. In starting an engine with cold oil the pump pressure is high; this pressure falls as the body of the oil is reduced, first, by the heat taken from the piston and cylinders; second, from the heat generated by the oil in working through the system and bearings, and third, by the gasoline vapor that has leaked by the rings has recondensed and is held by the oil.

The heat of a bearing, not affected by outside temperatures, is largely due to the fluid friction of the lubricant, the rule being that the heavier the body of the oil, the higher will be the heat due to friction. With the same lubricant on a bearing an increased flow will reduce the heat by simply carrying it away and not allowing it to accumulate; there is, therefore, an automatic adjustment in the forced feed system with a heavy oil—as a bearing heats, the oil feed increases due to the oil becoming lighter in body, and this increased feed tends to reduce the temperature of the bearing and as the temperature is reduced the body of the oil gets heavier and the flow is checked. It is only necessary to have a large enough supply of oil and a sufficiently large pump to work with any clearance

to make over-heating almost impossible except in the case of accident.

The temperature range of oil in the crank case of the Curtiss Oxx2 engine on these tests was from 110 to 140 degrees F.; on the Hall-Scott, 115 to 165 degrees F., and on the Sturtevant, 180 to 192 degrees F. The viscosities of oil A and oil D, representing nearly the heaviest and lightest oils used on the entire test, were as follows:

Product	Viscosity At 100 degrees F. Sec.	At 130 degrees F. Sec.	At 212 degrees F. Sec.
Oil A	1,780	706	138
Oil D	906	381	91

In fitting an oil to a certain clearance, to be at all effective, there must be taken into consideration the body of the oil and the temperature. After once securing the necessary balance between these three factors, the change of any one will upset the proposition. It seems wise, therefore, to consider building and operating the engines with one standardized oil kept in uniform condition, one standardized set of clearances and to keep the oil at as uniform temperature as is practicable.

GENERAL.

In working down the results of the tests so that a solution of the problem can be found, the tests that are reported on sheet No. 30 as giving only "fair" and "poor" lubrication will be eliminated. This leaves seven tests on the Curtiss V2C10, three tests on the Curtiss V2C3, four tests on the Curtiss Oxx2 and four tests on the Hall-Scott engine. Data from all these tests reported upon as giving good lubricating results, enters into the following discussion.

The Curtis V2C3 engine was the hardest to lubricate of all the engines tested. The fact that it has been generally found necessary to lubricate all Curtiss engines of this size with mixtures of castor and heavy mineral oil justifies the con-

clusion that this particular make of engine could be taken as being representative of this classification of engine as far as difficult lubrication requirements are concerned, for the reason that any operator examining the engine after any one of the runs, where the rings were stuck and the piston scored, would, in the light of the present practice, immediately start the engine off on a mixture of castor and heavy mineral oil. Of the eight oils tested on this engine only two have perfect records—test No. 19 with a medium amount of the semi-hard carbon and No. 30 with a slight amount of the hard carbon. A very close analysis of the results on this one engine is used in deciding the ultimate specification.

The Oxx2 Curtiss engine shows tests No. 10 and No. 13 with the best records. It is unfortunate that this engine went out of commission before the program of tests could be carried out, especially as this engine being small in size would have given some very interesting data with the high specific gravity oils. This engine was used for the test on the reclaimed oil which shows one tight piston ring but otherwise presents a perfect record. A very close analysis of the tests Nos. 10 and 13 on this engine will help to influence the final specification.

The Curtiss V2C10 was a new engine right from the shops, and all oils gave good results with a medium quantity of carbon which varied in nature. Study of the results of the tests on this engine shows that the consumption of oil is, entirely and only, related to the body of the oil as indicated by the viscosity at 212 degrees F. The two curves, representing consumption and viscosity, are exactly opposed at all points. It is, therefore, possible, knowing the consumption per horsepower hour of a light and a heavy oil, to chart a viscosity curve from which to secure the consumption of any intermediate viscosity oil. The effect of the absorption of gasoline between high specific gravity oil, No. 17, and low specific gravity oil, No. 32, with the amount of gasoline recovered from each oil is of interest.

Specific Gravity	Test No.	Viscosity at 100 degrees F. Saybolt New	Viscosity at 100 degrees F. Saybolt 5 hrs.	Flash New	Flash 5 hrs.	Gasoline
		Sec.	*Sec.*	*Deg. F.*	*Deg. F.*	*Per cent*
High	17	1,695	1,432	342	220	0.25
Low	32	1,744	1,416	460	212	1.75

This illustrates the entire effect upon Viscosity and flash of the absorption of gasoline.

The series of tests upon the Hall-Scott engine was of a highly satisfactory nature as it was possible to run through more than the regular program on this engine, and full and interesting data was secured. The highest flash and fire test oil gave the poorest lubrication and, with one exception, the oils listed as giving only fair lubrication were the high fire test oils. The oils on tests 31 and 32 can be selected as having produced the best effect as these oils are reported as making a semi-hard carbon of slight quantity, the lubrication being good in each case. The natures of these two oils vary greatly and the results of the test on each are valuable in influencing the final specification.

CHARACTERISTICS REQUIRED.

It is necessary to have an oil for this work that will change the least while working in the engine. This oil must also leave the engine clean and well lubricated. Any objectionable amount of carbon that is formed by the oil should pass out of the exhaust and not remain in the engine, and that carbon which does remain in the engine must not build up into ridges or be hard and adhesive, but must be loose and flaky and easily removed. The cold or pour test of the oil should also be as low as possible. Such an oil should also be easily and readily reclaimed, and after reclaiming, should work in the engines at least as well as the original oil.

It is necessary, due to the difference in the absorbent qualities and to the characteristic difference in the viscosity curves

of both classes of oils, to specify that the paraffine base oil be somewhat heavier in viscosity at 212 degrees F. than the asphaltic or naphthene base oils, so that it will be possible to standardize clearances on the basis of the body of the oil being the same in the engine at working temperatures irrespective of classification of the crude. The indication of the crude will be taken from two factors—specific gravity, and the cold or pour test. The chart, sheet No. 1, shows the relation of these factors to the Conradson carbon test, the Waters test and to the viscosity at 212 degrees F.

Oils classed as "high specific gravity oils" shall be those having a specific gravity above .9100 (or below 24 degrees Baumé conversion by the Tagliabue Manual 9th Edition, or below 23.85 degrees Baumé conversion by the Bureau of Standards' conversion table, circular No. 57); the pour test shall be below 15 degrees F. by the method of the American Society for Testing Materials.

Oils classed as "low specific gravity oils" shall be those having a specific gravity below .9100 (or above 24 degrees Baumé conversion by the Tagliabue Manual 9th Edition, or above 23.85 degrees Baumé conversion by the Bureau of Standards' conversion table, circular No. 57); the pour test shall be above 15 degrees F. by the method of the American Society for Testing Materials.

SPECIFICATIONS.

The object of this work was to allow preparation of a specification covering a suitable mineral lubricating oil for use on aircraft engines of the stationary cylinder type. After careful consideration of all the facts presented by the various tests with facts that have been deduced from the experiments on reclaiming as well as those that have resulted from the very complete gasoline tests which have been part of this general work but have been reported upon separately, and considering also the supply of oil and the price, and, in the actual writing of the specifications, eliminating all those factors that have no

bearing on the subject, the specification shall consist in its essential parts as follows:

The Liberty Aero Oil shall be a pure, highly refined petroleum product, neutral in action and shall not show the presence of moisture, sulphonates, soap, resin or tarry constituents which would indicate adulteration or lack of proper refining. This oil shall be suitable in every way for the entire lubrication of stationary cylinder aero engines operating under all conditions. The viscosity of the finished oil at 212 degrees F. on the Saybolt Universal Viscosimeter shall be from 85 to 90 seconds for the low specific gravity oils and from 70 to 75 seconds for the high specific gravity oils. The flash point of the finished oil shall be over 350 degrees F. in the Cleveland open cup. The pour test for the low specific gravity oils shall not be over 40 degrees F., and for the high specific gravity oils not over 15 degrees F. The oil shall not contain or show a carbon residue of over 1.5 per cent by the modified Conradson method, and the nature of the carbon shall be loose and flaky and shall easily break up in the crucible, and the oil must be clear of water after one ounce of oil and one ounce of distilled water, heated at 180 degrees F. are shaken vigorously for five minutes and left standing for one hour.

Reprints describing the above referred to apparatus and methods will be furnished with the specifications.

CONCLUSION.

It is necessary, in order to balance all factors, to use a very extra heavy oil, and this oil should be placed in the engine after it has been heated to 160 degrees F. In order to more readily accomplish the result for which hot oil is put in the engine, hot water should also be put in the water circulating system. This heating up of the engine should be the established practice summer and winter wherever possible; and the necessary equipment should always accompany the squadron to make this possible. All oil should be removed from the engines every night and should be sent to the reclaimers for

removal of the residue and heavy ends of the gasoline. Reclaiming stations should be established at the flying fields and should accompany the base supply depots in active service. All of this care is for the good of the engine, to relieve the strain in starting and to keep the oil in the very best of condition so that nothing can possibly happen on account of lubrication or the failure of the lubricating system.

We can absolutely depend upon our American oil refiners to furnish us with the finest oils that it is possible to produce, made up in accordance with the above specification; and with the care in handling in the field, which will be assured by the very complete oil house and supervising system, it can be stated that the oil man can go no further with the service that he can render. An oil that has been scientifically developed, produced and used will always give 100 per cent lubrication value.

WILLIAM F. PARISH, A. M. E., S. S. L.,
Signal Corps, United States Army, Equipment Division, Specification Sec.
Washington, D. C., December 28, 1917.

Before submitting this report to the officer to whom it is directed, a conference was had with the following officers and representatives of the U. S. Navy, officers and representatives of the Signal Corps of the U. S. Army, and the producers members of Committee D-2 on Lubricants of the American Society for Testing Materials:

U. S. Navy—Commander J. O. Fisher, Lieut. C. K. Mallory, J. G. O'Neil, Chief Chemist, Engineering Experiment Station, U. S. N., Annapolis, Md.

U. S. Army—Major Guy L. Gerhart, Signal Corps, U. S. A.; Capt. O. J. May, Signal Corps, A. S., U. S. A.; Geo. F. Fenno, A. M. E., S. S. L.; Wm. F. Parish, A. M. E., S. S. L.

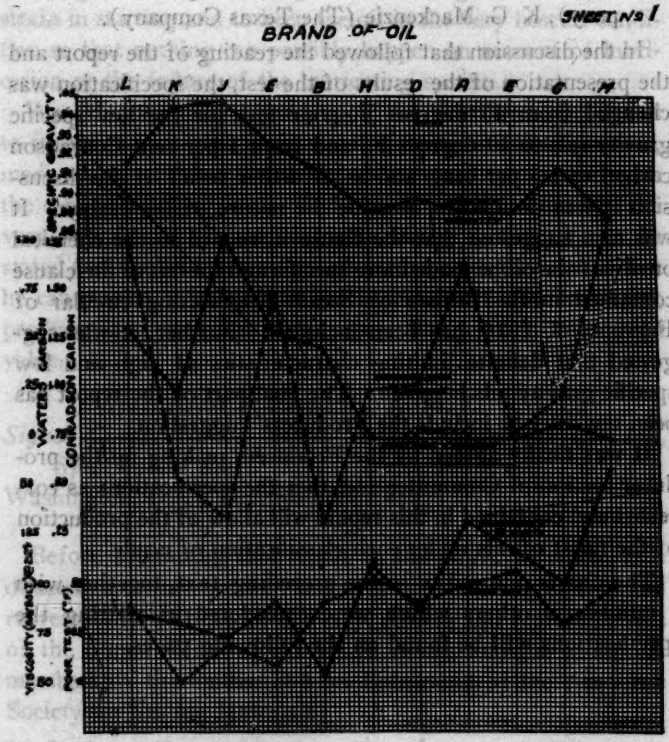
Producer Members of Committee D-2.

American Society for Testing Materials—P. H. Conradson (Galena-Signal Oil Company), F. R. Baxter (Vacuum Oil Company), F. C. Robinson (Atlantic Refining Company), K. G. Mackenzie (The Texas Company).

In the discussion that followed the reading of the report and the presentation of the results of the test, the specification was changed from 45 degrees F. pour test for the low specific gravity oils to 40 degrees F., and from 1 per cent Conradson carbon to 1.5 per cent, and as a further result of the discussion it was decided to describe the nature of the carbon. It was also suggested that the clause in regard to the chemical purity of the oil be made more specific and therefore the clause contained in the Bureau of Steam Engineering circular of February 7, 1916, has been included. Further, it was suggested that definite limiting characteristics of high and low specific gravity oils be given. The final part of the report has been rewritten to include the Producers' suggestion.

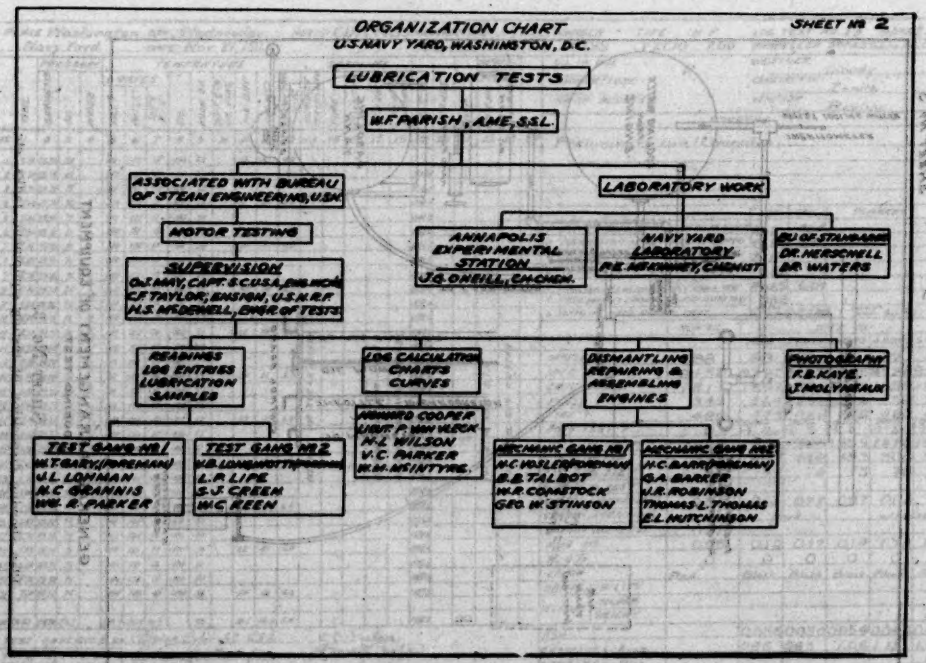
It was finally agreed by the Producers making up the producer section of Committee D-2 that the specifications as corrected and contained in this report will allow of the production of the finest of oils under each classification of crude.

The charts referred to in the preceding text, together with a number of others which were considered in writing the specifications will be found on the following pages.



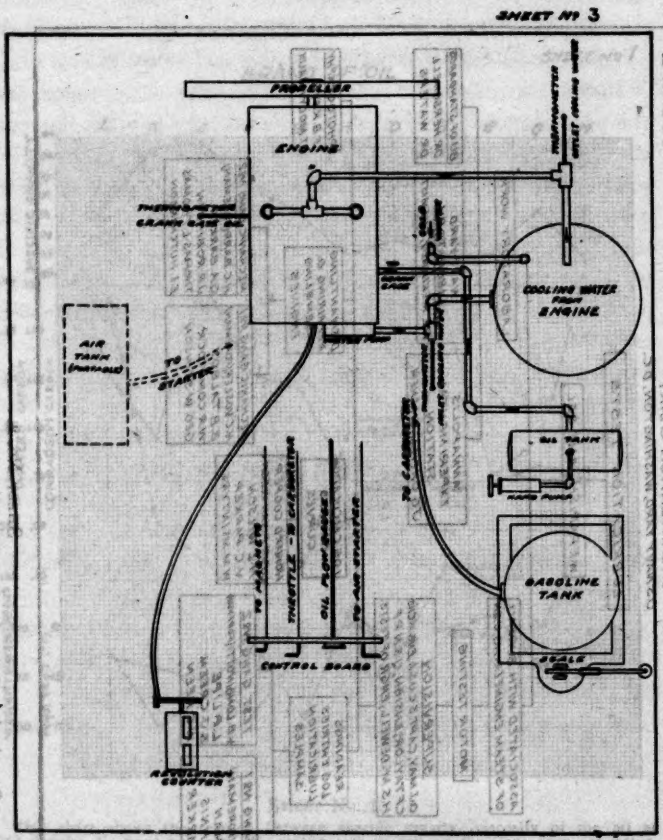
SHEET No. 1.

This chart shows the relation between specific gravity, viscosity of the oil at 212 degrees F., pour test, and the carbon test as run on the Conradson apparatus, which has been approved by the A. S. T. M. and the Bureau of Standards Waters' carbon test. It will be noted that the Waters test follows generally the line of specific gravity and that the Conradson test follows the line of viscosity.



SHEET No. 2.

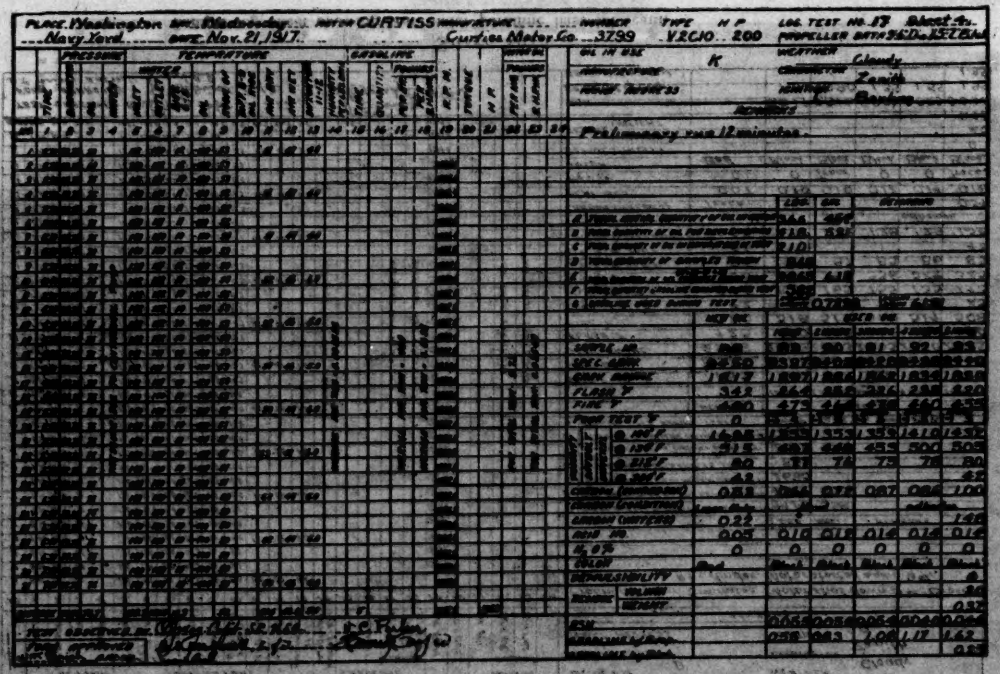
Organization chart, showing disposition made of the experts in conducting the entire series of tests.



GENERAL ARRANGEMENT OF EQUIPMENT
DURING TEST

Sheet No. 3.

Plan showing disposition of testing equipment, tanks, etc.



SHEET No. 4.

Sample log sheet selected to show the test under asphaltic base lubricant.

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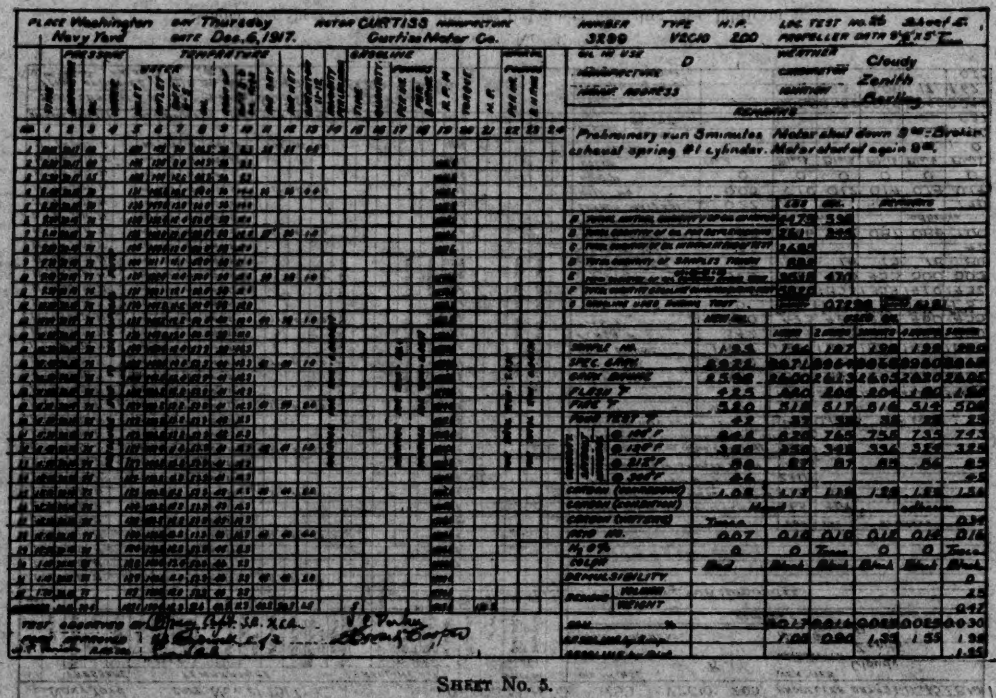

PLACE Washington Navy Yard DAY Thursday DATE Dec. 6, 1917. MOTOR CURTISS MANUFACTURER Curtiss Motor Co. NUMBER 3X99 TYPE V2CJO H.P. 200 LOG TEST NO. 26 PROPELLER DATA 9'2"x5'7"

OIL IN USE D LUBRICATOR INJECTOR WEIGHT GROSS WEATHER CONDITION Cloudy WIND Zenith Ceiling

REMARKS

Preliminary run 3 minutes. Motor shut down 9 AM. Throttle exhaust spring #1 cylinder. Motor started again 9 AM.

1	200	200	70		60	62	70	100	82	82	82	82													
2	200	200	70		60	62	70	100	82																
3	200	200	70		60	62	70	100	82																
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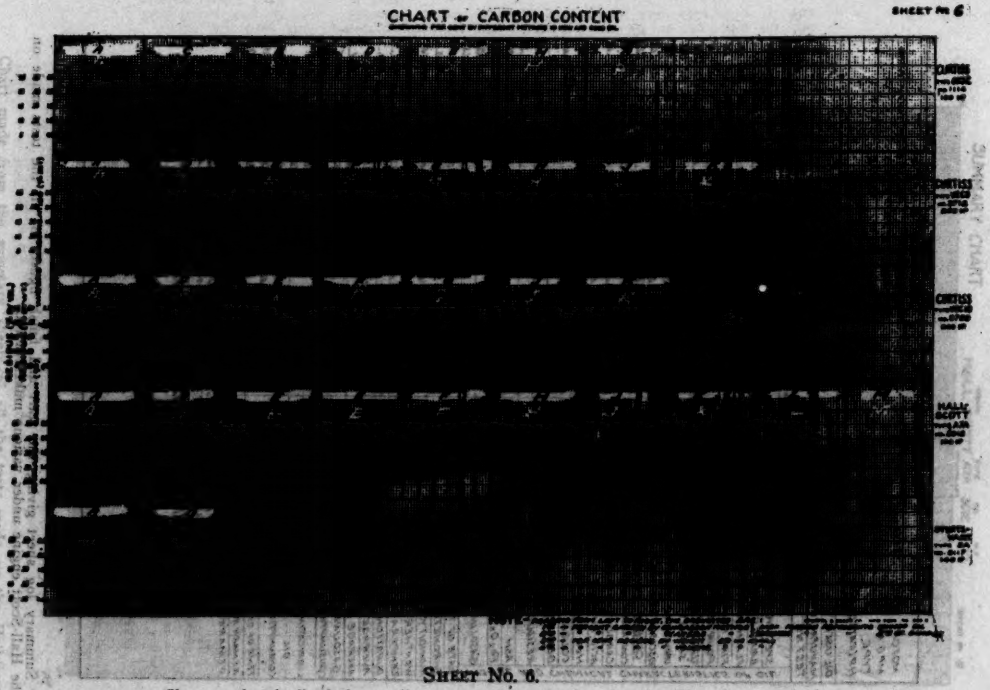
282	200	200	70		60	62	70	100	82																
283	200	200	70		60	62	70	100	82					

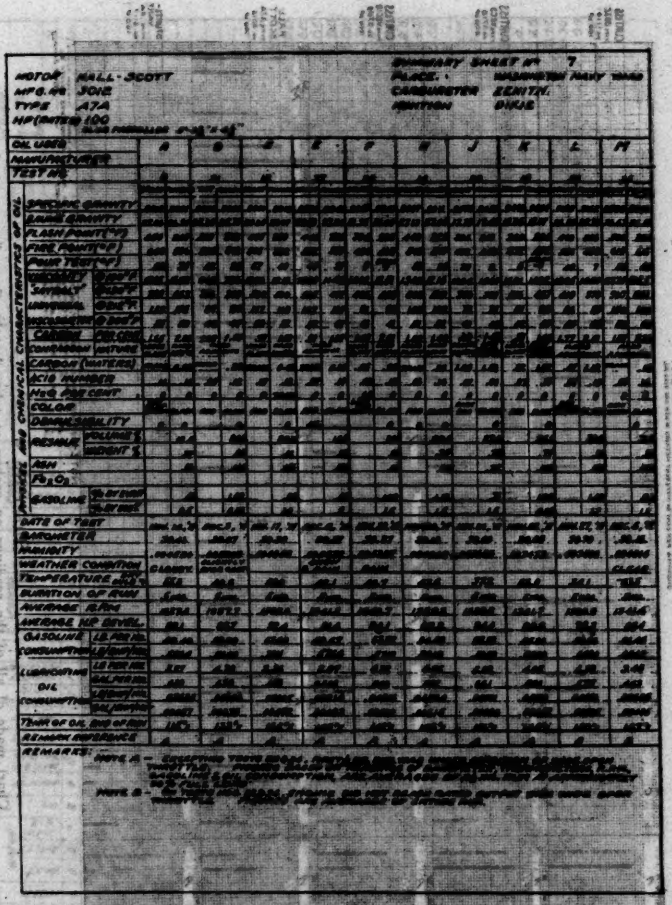
SHEET No. 5.

Sample log sheet showing test under paraffine base lubricant.



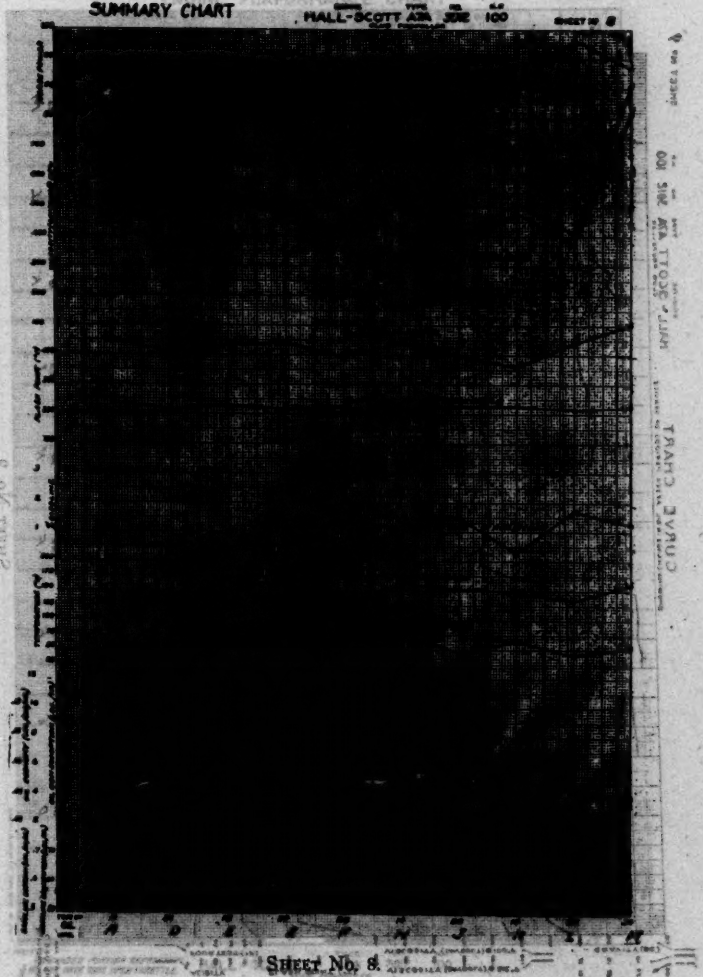
SHEET No. 6.

Chart made of all of the readings on carbon as taken by the Conradson method (A. S. T. M.) and the Waters method (Bureau of Standards), percentage of residue by weight and percentage of residue by volume (Tidewater method).



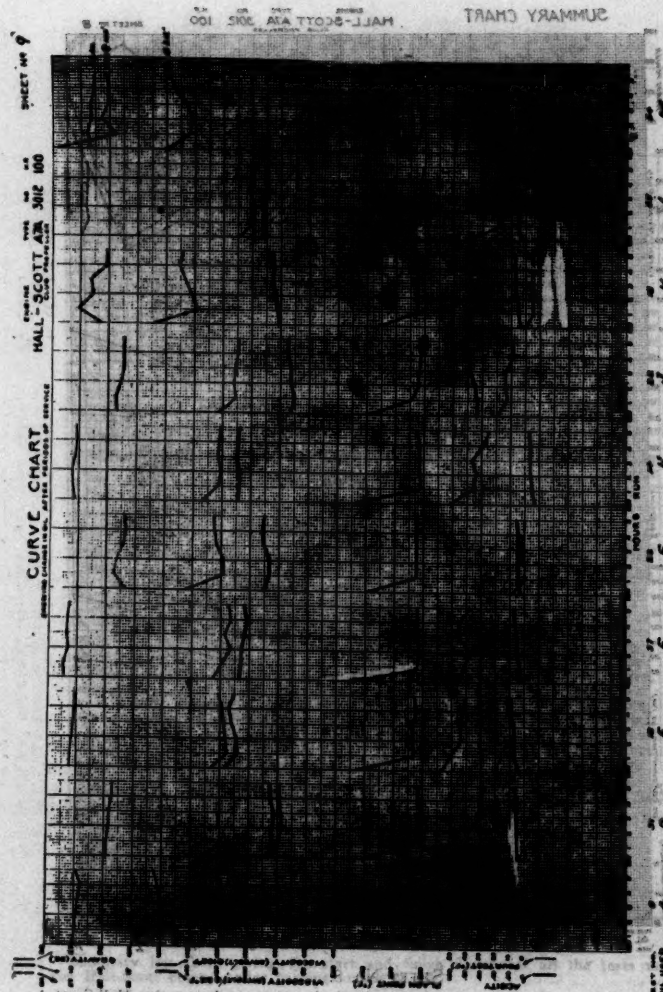
SHEET No. 7.

Summary log sheet giving the start and finish figures of all the tests made on the Hall-Scott engine under various makes of oil.



SHEET No. 8.

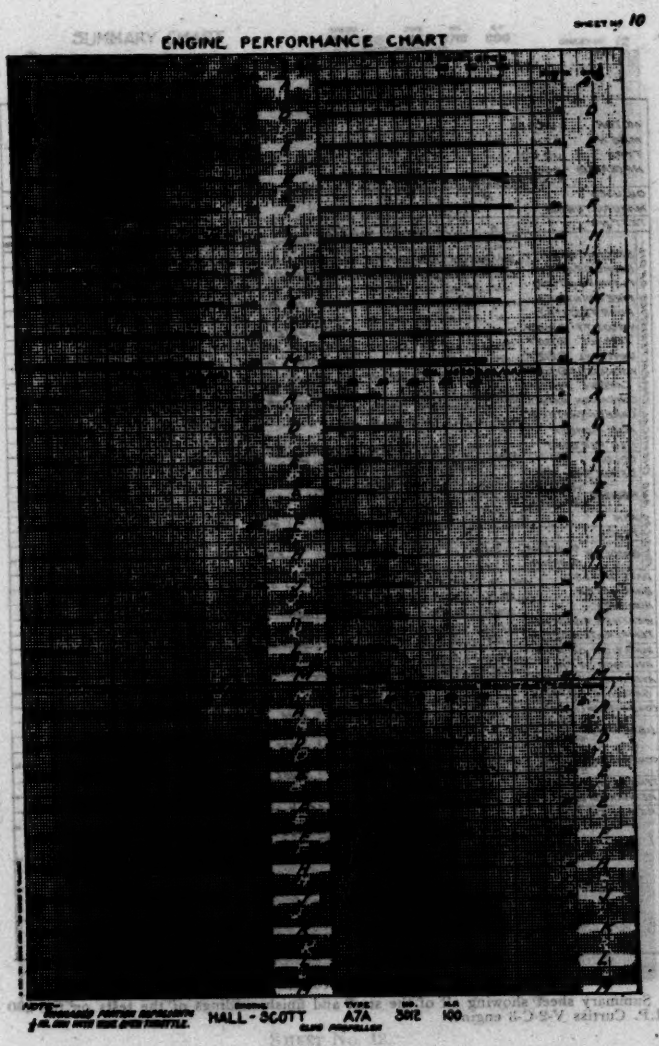
Chart made from the summary sheets of all the tests made on the Hall-Scott engine. This chart shows the changes that have taken place in the viscosity of the oil while in the engine and of the flash point of the oil while operating. It also gives the average running data of the main conditions of the test.



SHEET No. 9.

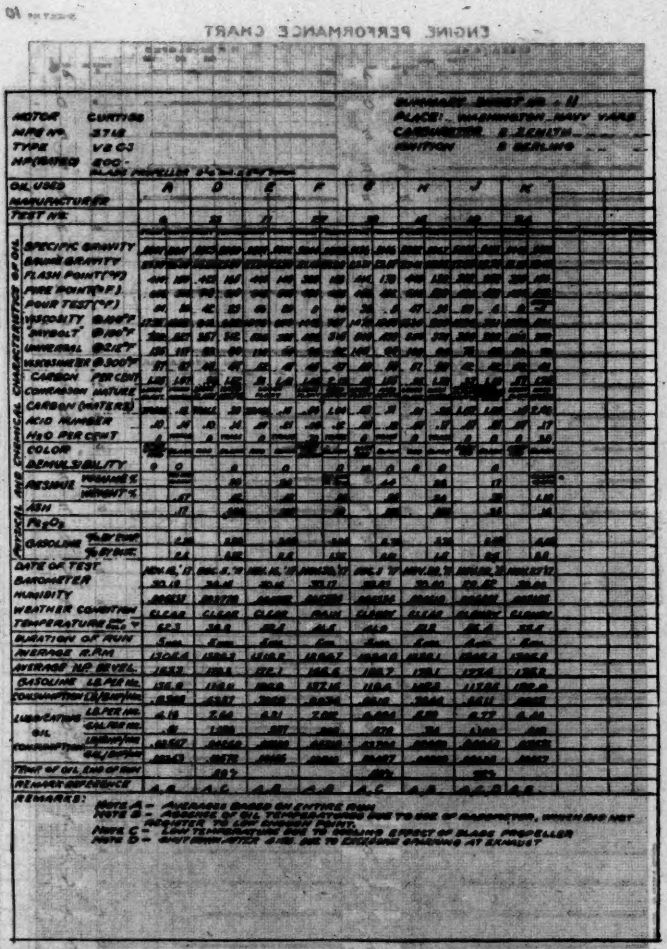
Chart showing the complete physical characteristics of all of the oils on the Hall-Scott engine test. Samples taken every hour during the operation of the engine under each series of tests.

Chart showing the complete physical characteristics of all of the oils on the Hall-Scott engine test. Samples taken every hour during the operation of the engine under each series of tests.



SHEET No. 10.

Chart showing comparison between all of the main conditions on the Hall-Scott engine test with the various oils in use.



ENGINE PERFORMANCE CHART

SUMMARY SHEET NO. 11

MOTOR CURTISS
MFG NO. 3718
TYPE V-2 C-3
HP (RATED) 200 -
BLADE PROPELLER 8'6" DIA. 8 PITCH

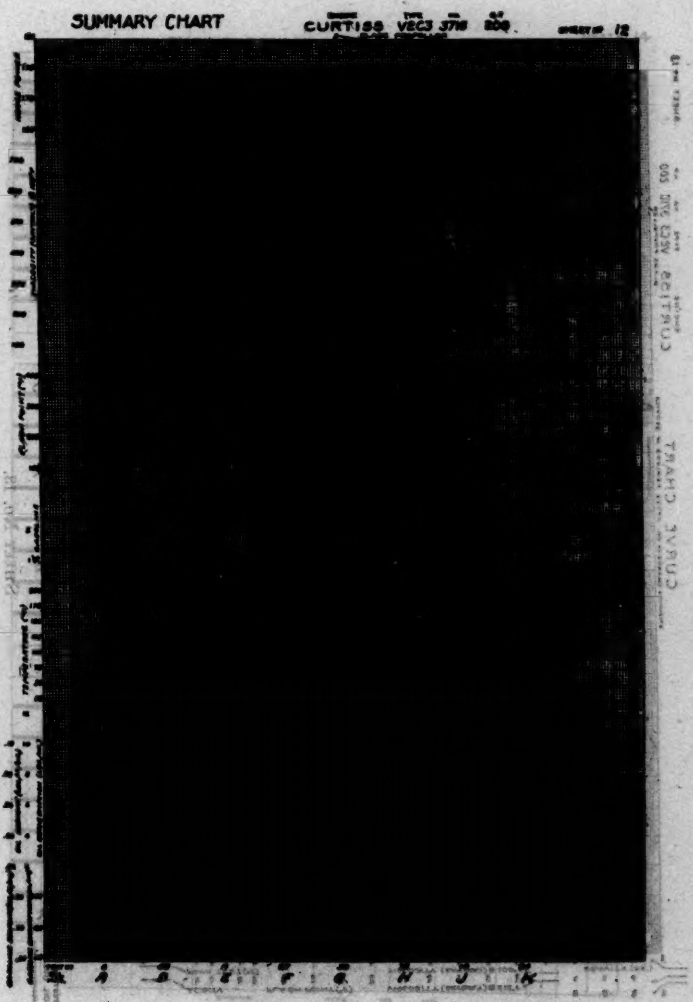
PLACE: WASHINGTON NAVY YARD
CARBURETOR S. ZENITH
IGNITION S. BERLING

OIL USED	A	D	C	F	G	H	J	K
MANUFACTURER								
TEST NO.	9	22	21	27	28	24	29	26
PHYSICAL AND CHEMICAL CHARACTERISTICS OF OIL: SPECIFIC GRAVITY								
BAUME GRAVITY								
FLASH POINT (°F)	440	440	420	440	440	440	420	420
FIRE POINT (°F)	490	490	490	490	490	490	490	490
POUR TEST (°F)	20	15	20	25	25	25	0	0
VISCOSITY SAYBOLT @ 100°F	1230	1230	1230	1230	1230	1230	1230	1230
SAYBOLT @ 210°F	220	220	217	220	220	220	220	220
UNIVERSAL @ 210°F	150	150	150	150	150	150	150	150
VISCOSIMETER @ 300°F	57	57	56	57	57	57	56	56
CARBON PER CENT	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
CONRADSON NATURE								
CARBON (WATERS)		.10		.10	.10	.10	.10	.10
ACID NUMBER	.10	.10	.10	.10	.10	.10	.10	.10
H2O PER CENT	0	0	0	0	0	0	0	0
COLOR								
EMULSIBILITY	0	0	0	0	0	0	0	0
RESIDUE VOLUME %								
RESIDUE WEIGHT %		.17	.15	.15	.15	.15	.15	.15
ASH		.11	.09	.09	.09	.09	.09	.09
Fe_2O_3								
GASOLINE "FLOW CHART" % BY VOL.		2.0	2.0	2.0	2.0	2.0	2.0	2.0
		2.0	2.0	2.0	2.0	2.0	2.0	2.0
DATE OF TEST	NOV 16, '17	DEC 3, '17	NOV 30, '17	NOV 30, '17	DEC 7, '17	NOV 28, '17	NOV 28, '17	NOV 27, '17
BAROMETER	30.10	30.20	30.16	30.17	30.25	30.20	29.80	30.04
HUMIDITY	.00032	.00278	.00098	.00098	.00032	.00098	.00098	.00098
WEATHER CONDITION	CLEAR	CLEAR	CLEAR	RAIN	CLEAR	CLEAR	CLEAR	CLEAR
TEMPERATURE DEG. F	62.5	38.8	59.2	54.5	41.0	53.2	55.4	55.4
DURATION OF RUN	5 min.	5 min.	5 min.	5 min.	5 min.	5 min.	5 min.	5 min.
AVERAGE R.P.M.	1210.0	1208.2	1210.0	1208.2	1208.2	1208.2	1208.2	1208.2
AVERAGE H.P. BY VEL.	183.3	180.1	178.1	168.6	180.7	178.1	177.4	178.1
GASOLINE LB. PER HR.	156.6	156.6	156.6	157.16	156.6	149.2	151.86	150.8
CONSUMPTION LB/Gal/Hr.	.8508	.8697	.8660	.8696	.8660	.8244	.8411	.8355
LUBRICATING OIL LB. PER HR.	6.18	7.64	6.21	7.02	6.864	6.88	6.77	6.88
OIL GAL. PER HR.	.8	1.009	.827	.935	.979	.94	1.006	.935
CONSUMPTION Lubricating Oil / Gal/Hr.	.00767	.00760	.00769	.00769	.00769	.00769	.00769	.00769
	.00767	.00757	.00765	.00765	.00767	.00765	.00765	.00767
TEMP OF OIL END OF RUN		220			220		220	
REMARK REFERENCE	A.B.	A.C.	A.B.	A.B.	A.C.	A.B.	A.C.D.	A.B.

REMARKS:
NOTE A - AVERAGES BASED ON ENTIRE RUN
NOTE B - AVERAGE OF OIL TEMPERATURES DUE TO USE OF RADIATOR, WHICH DID NOT
ADJUSTED TO LOW END OF SCALE (60°F).
NOTE C - LOW TEMPERATURE DUE TO COOLING EFFECT OF BLADE PROPELLER
NOTE D - SHUT DOWN AFTER 4 MIN. DUE TO EXCESSIVE SMOKING AT EXHAUST

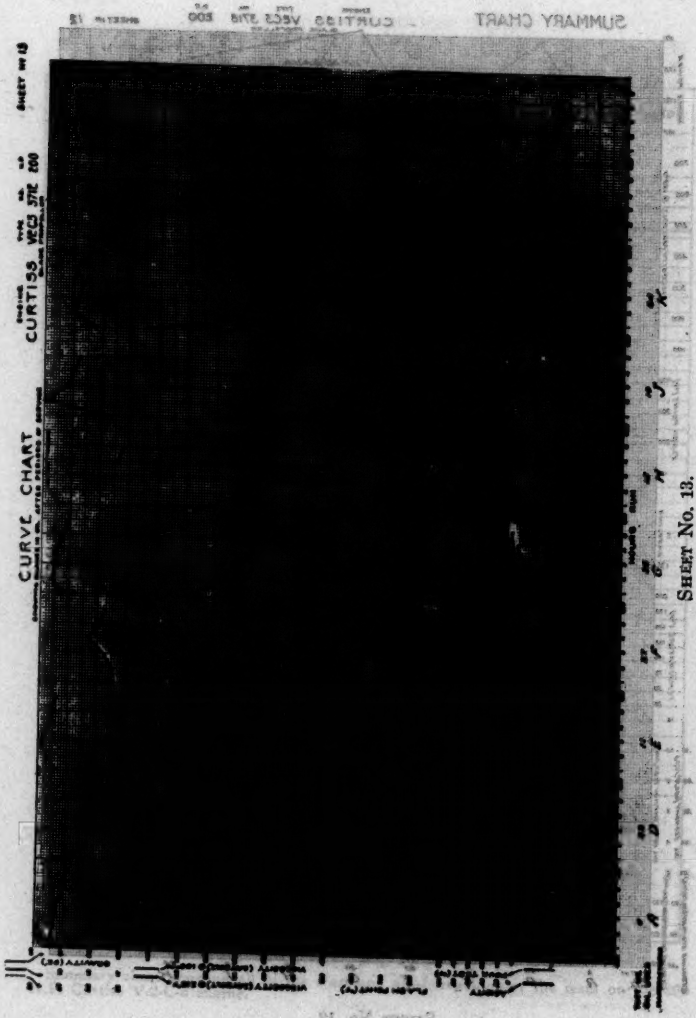
Sheet No. 11.

Summary sheet showing all of the start and finish readings of the tests on the 200 H.P. Curtiss V-2-C-3 engine.



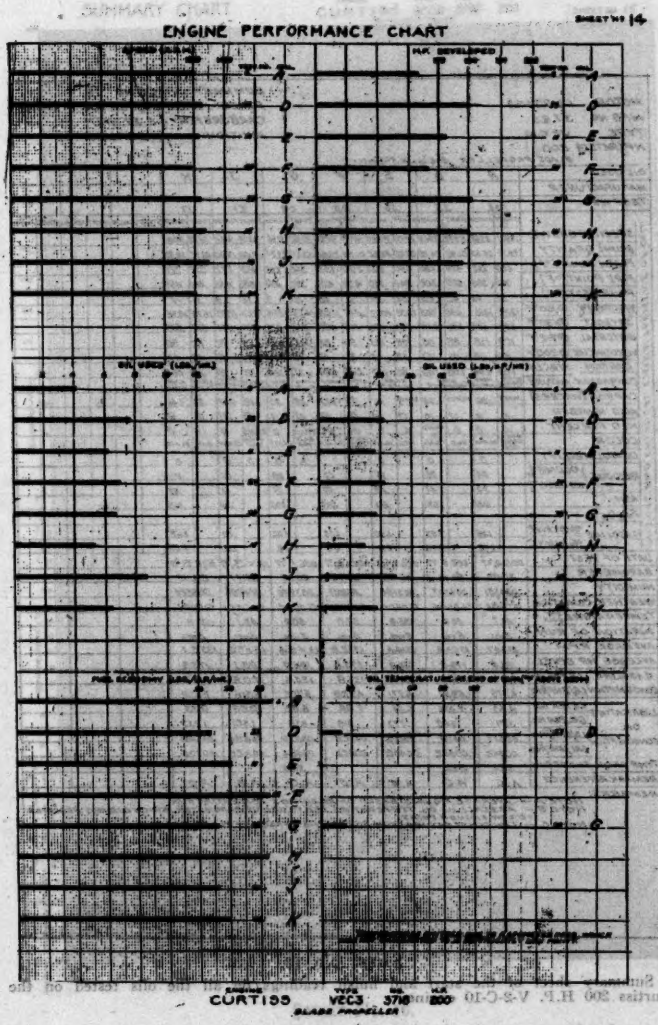
SHEET No. 12.

Summary chart made of the main readings of the summary sheet, showing particularly the change which has taken place between the new and old oil in viscosity at 130 degrees F. and in the flash point, on the test of the Curtiss 200 H.P. engine.



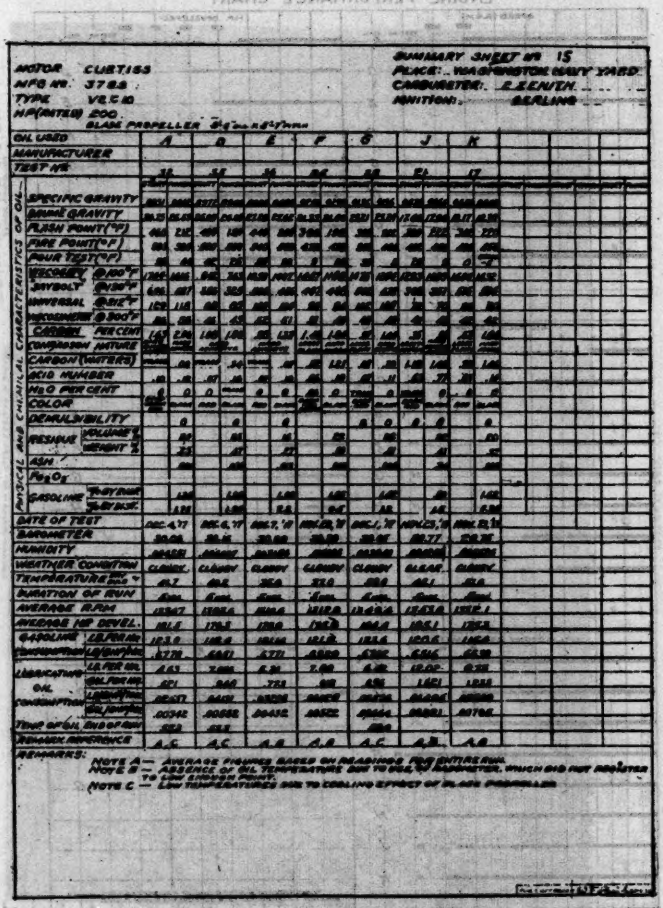
SHEET No. 13.

Chart made up of all the readings on the oils taken at hourly intervals and compared with the new oil on test of the Curtiss 200 H.P. engine.



SHEET No. 14.

Chart showing engine performance of the Curtiss 200 H.P. engine with different kinds of oil.



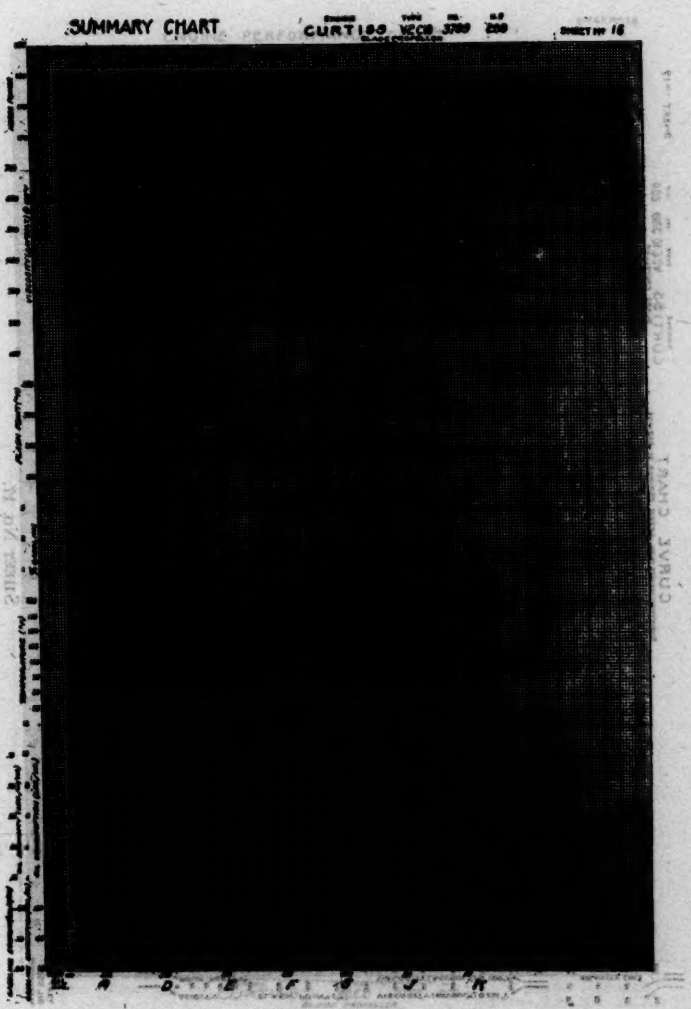
MOTOR CURTISS — SUMMARY SHEET NO 15
NPS NO. 3785 — PLACE: HAMPTON ROADS NAVY YARD
TYPE V-2-C-10 — CARBURETER: ZENITH
H.P.(RATED) 200 — IGNITION: BERLING
BLADE PROPELLER

OIL USED	A	B	E	F	G	J	K
MANUFACTURER							
TEST NO.	35	34	36	30C	33	31	17
PHYSICAL AND CHEMICAL CHARACTERISTICS OF OIL — SPECIFIC GRAVITY	.8851	.8866	.8777	.8868	.8866	.8778	.8751	.8741	.8754	.8744	.8868
BAUME @ GRAVITY	28.35	28.25	30.69	28.25	27.98	29.82	30.26	30.51	29.94	30.06	28.17	28.35
FLASH POINT (°F)	405	395	400	380	395	395	390	395	395	395	395	395
FIRE POINT (°F)	455	455	460	440	455	455	455	455	455	455	455	455
POUR TEST (°F)	20	25	0	25	20	25	0	25	5	25	0	-5
SAYBOLT @ 100°F	1305	1305	1240	1305	1290	1290	1290	1290	1290	1290	1290	1290
SAYBOLT @ 210°F	60.6	60.7	58.0	60.7	60.4	60.5	60.5	60.5	60.5	60.5	60.5	60.5
UNIVERSAL @ 210°F	102	110	98	102	102	102	102	102	102	102	102	102
ENGLER @ 200°F	8.6	8.8	8.5	8.5	8.5	8.7	8.7	8.7	8.7	8.7	8.7	8.7
CARBON RESIDUE PERCENT (CONRADSON METHOD)	1.45	1.26	1.68	1.80	1.80	1.68	1.84	1.84	1.68	1.68	1.68	1.68
CARBON (WATERS)												
ACID NUMBER	.15	.15	.17	.15	.15	.15	.15	.15	.15	.15	.15	.15
H2O PER CENT	0	0	0	0	0	0	0	0	0	0	0	0
COLOR	Dk Grn	Dk Grn	Dk Grn	Dk Grn	Dk Grn	Dk Grn	Dk Grn	Dk Grn	Dk Grn	Dk Grn	Dk Grn	Dk Grn
DEMULSIBILITY		0		0			0	0	0	0		0
RESIDUE VOLUME %		92		92		92		92		92		92
RESIDUE WEIGHT %		93		93		93		93		93		93
ASH		.04		.04		.04		.04		.04		
Fe_2O_3												
GASOLINE BY RUN		1.25		1.25		1.25		1.25		1.25		1.25
GASOLINE BY DIST.		1.25		1.25		0.5		1.0		1.0		0.25
DATE OF TEST	DEC. 4,'17	DEC. 6,'17	DEC. 7,'17	DEC. 28,'17	DEC. 29,'17	DEC. 1,'17	NOV. 25,'17	NOV. 27,'17	NOV. 28,'17	NOV. 29,'17	NOV. 30,'17	DEC. 2,'17
BAROMETER	30.06	29.95	30.06	29.89	29.89	29.97	29.77	29.76	29.76	29.76	29.76	29.76
HUMIDITY	GRASS	GRASS	GRASS	GRASS	GRASS	GRASS	GRASS	GRASS	GRASS	GRASS	GRASS	GRASS
WEATHER CONDITION	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR
TEMPERATURE (DEG °F)	49.7	49.5	35.0	33.0	33.0	49.1	49.1	49.1	49.1	49.1	49.1	49.1
DURATION OF RUN	4 hrs.	4 hrs.	4 hrs.	4 hrs.	4 hrs.	4 hrs.	4 hrs.	4 hrs.	4 hrs.	4 hrs.	4 hrs.	4 hrs.
AVERAGE R.P.M.	1594.7	1598.4	1598.4	1598.8	1598.8	1594.8	1594.8	1594.8	1594.8	1594.8	1598.8	1598.8
AVERAGE H.P. DEVEL.	191.5	176.3	178.0	178.3	184.8	185.1	178.3
GASOLINE LB. PER HR.	18.3.0	18.1.4	18.1.44	18.1.8	18.3.4	18.0.6	18.6.8
CONSUMPTION GALLONS	6776	6461	6771	6589	6782	6546	6638
LUBRICATING OIL LB. PER HR.	4.63	7.88	5.31	7.88	6.38	12.00	8.38
CONSUMPTION GALLONS	821	848	753	848	676	1421	1014
TIME OF OIL END OF RUN	09:57	04:01	03:58	04:02	03:54	04:06	03:59
TIME OF OIL END OF RUN	.01342	.00982	.00432	.00822	.00644	.00821	.01706
TIME OF OIL END OF RUN	09:3	09:5			09:4		
ENGINE REFERENCE	A.C.	A.C.	A.C.	A.C.	A.C.	A.C.	A.C.

REMARKS:
NOTE A — AVERAGE FIGURES BASED ON READINGS FOR ENTIRE RUN.
NOTE B — ABSENCE OF OIL TEMPERATURE DUE TO OIL TO BE USED, TEMPERATURE WHICH DID NOT REGISTER TO LOW SIDE OF SCALE.
(NOTE C — LOW TEMPERATURES DUE TO COOLING EFFECT OF PROPELLER.

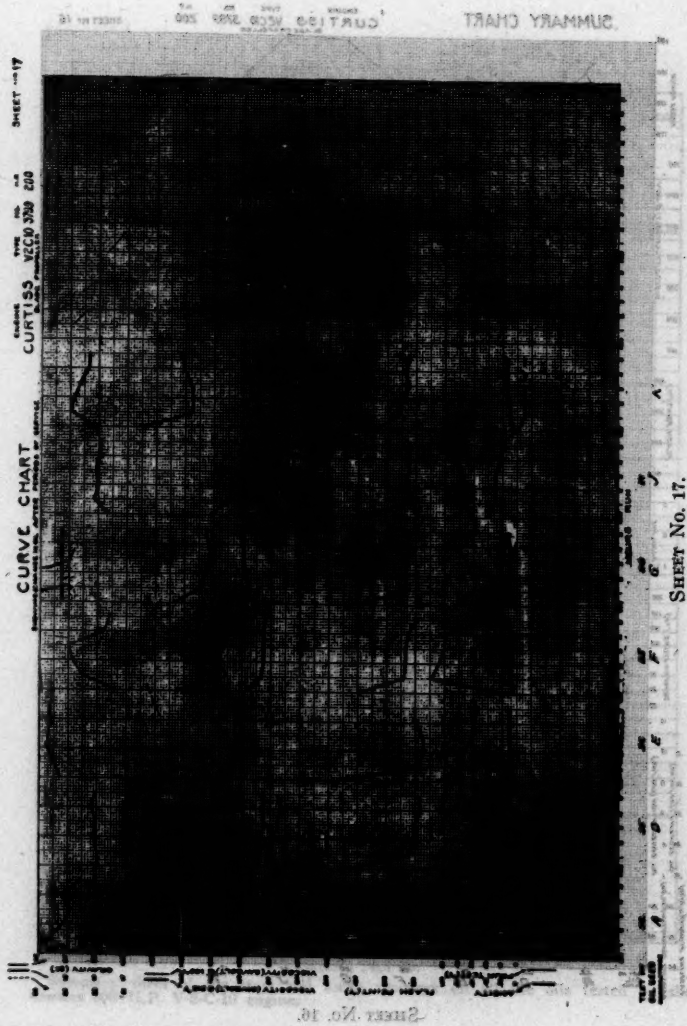
Sheet No. 15.

Summary sheet of the start and finish readings on all the oils tested on the Curtiss 200 H.P. V-2-C-10 engine.



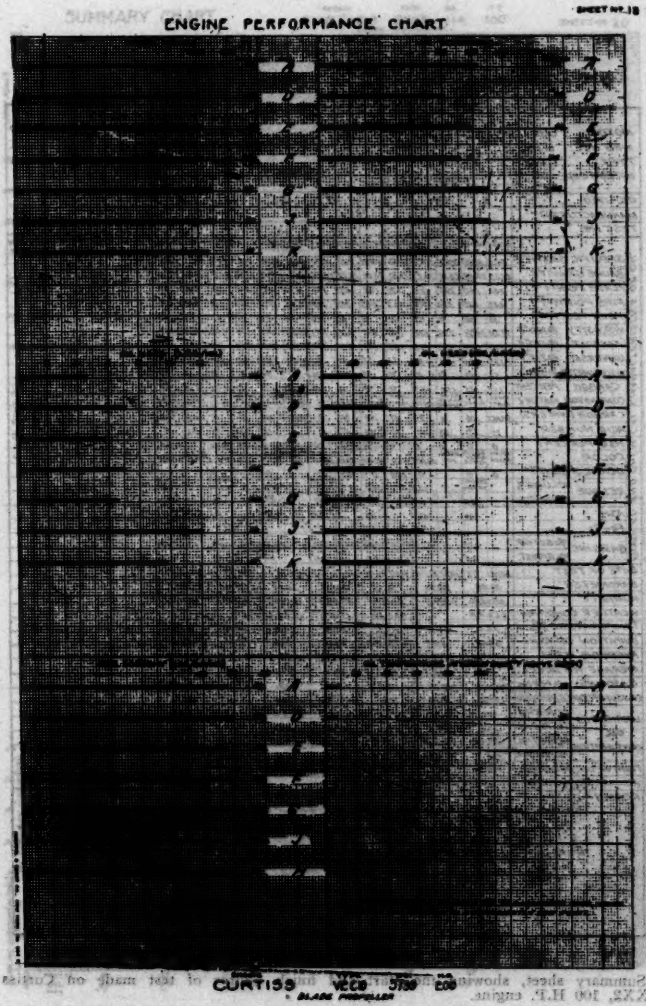
SHEET No. 16.

Chart made of main readings of summary chart, showing change that has taken place in the viscosity and flash point of the various oils during the test on the 200 H.P. V-2-C-10 engine.



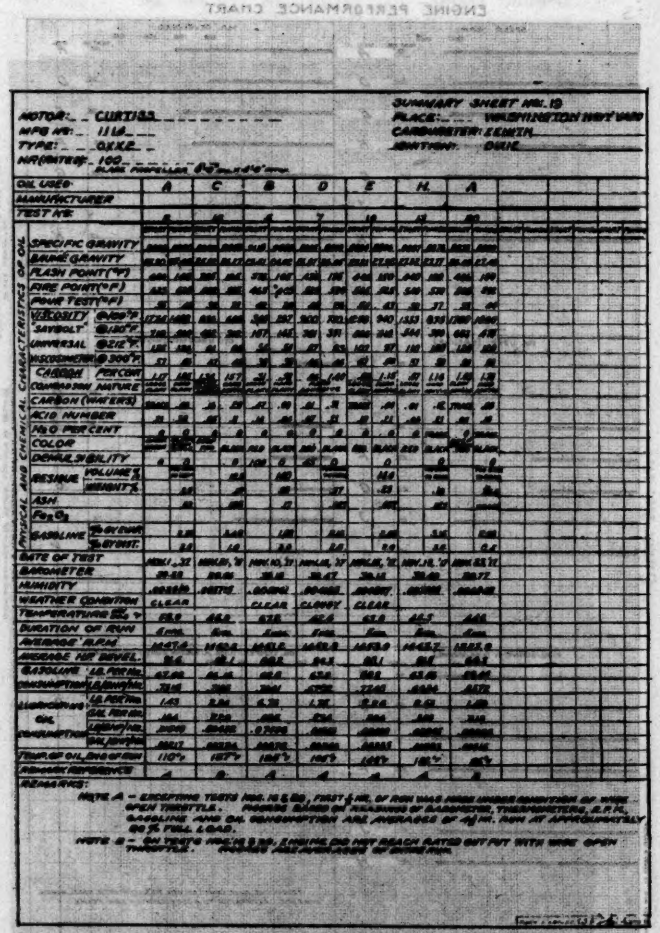
SHEET No. 17.

This chart shows the changes that have taken place in the oil during its operation in the Curtiss V-2-C-10, 200 H.P. engine.



SHEET No. 18.

Engine performance chart of the Curtiss V-2-C-10, 200 H.P. engine, showing various engine conditions while operating with the various oils.



ENGINE PERFORMANCE CHART

MOTOR:- CURTISS
MFG NO:- 1118
TYPE:- OXX2
NR(METER)#- 100
SUMMARY SHEET NO. 19
PLACE:- WASHINGTON HEIGHTS
CARBURETER: SMITH
IGNITION: DELCO

OIL USED	A	C	B	D	E	H	A				
MANUFACTURER											
TEST NO.	8	18	4	7	10	12	20				
PHYSICAL AND CHEMICAL CHARACTERISTICS OF OIL — SPECIFIC GRAVITY	.8998	.8998	.8998	.8998	.8998	.8998	.8998	.8998	.8998	.8998	.8998
BAUME GRAVITY	25.80	25.80	25.80	25.80	25.80	25.80	25.80	25.80	25.80	25.80	25.80
FLASH POINT (°F)	400	400	395	395	395	395	395	395	395	395	395
FIRE POINT (°F)	440	440	440	440	440	440	440	440	440	440	440
POUR TEST (°F)	25	25	25	25	25	25	25	25	25	25	25
VISCOSITY Engler's	1736	1482	1265	1265	1265	1265	1265	1265	1265	1265	1265
VISCOSITY Saybolt	8180	6980	5960	5960	5960	5960	5960	5960	5960	5960	5960
VISCOSITY Universal	1180	1006	860	860	860	860	860	860	860	860	860
VISCOSITY @ 200°F	57	48	42	42	42	42	42	42	42	42	42
CARBON RESIDUE Percent	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12
CARBON RESIDUE Nature											
CARBON (WATERS)	trace	.05	.05	.05	.05	.05	trace	.05	.05	trace	.05
ACID NUMBER	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05
H2O PER CENT	0	0	0	0	0	0	0	0	0	0	0
COLOR	Dk. Amber	Dk. Amber	Dk. Amber	Dk. Amber	Dk. Amber	Dk. Amber	Dk. Amber	Dk. Amber	Dk. Amber	Dk. Amber	Dk. Amber
DENSITY @ 60°F	.9	.9	.9	1.00	.9	.90	.9	.9	.9	.9	.9
RESINE VOLUME %	0		0		0		0		0		0
RESINE WEIGHT %	.05		.05		.05		.05		.05		.05
ASH	.05		.05		.05		.05		.05		.05
Fe2O3											
GASOLINE % BY VOLUME	5.25	5.25	5.25	5.25	5.25	5.25	5.25	5.25	5.25	5.25	5.25
GASOLINE % BY WEIGHT	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
DATE OF TEST	NOV. 17	NOV. 17	NOV. 19	NOV. 19	NOV. 17	NOV. 17	NOV. 17	NOV. 19	NOV. 19	NOV. 19	NOV. 17
BAROMETER	29.55	29.55	29.45	29.45	29.47	29.47	29.47	29.45	29.45	29.45	29.47
HUMIDITY	.0025%	.0025%	.0040%	.0040%	.0040%	.0040%	.0040%	.0040%	.0040%	.0040%	.0040%
WEATHER CONDITION	CLEAR	CLEAR	CLEAR	CLEAR	CLOUDY	CLOUDY	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR
TEMPERATURE DEG. F	62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0
DURATION OF RUN	4 min.	4 min.	4 min.	4 min.	4 min.	4 min.	4 min.	4 min.	4 min.	4 min.	4 min.
AVERAGE R.P.M.	1447.4	1450.8	1451.2	1450.8	1452.0	1452.0	1445.2	1452.0	1452.0	1452.0	1447.4
AVERAGE HP DEVEL.	96.6	98.1	98.2	97.3	98.1	98.1	96.6	98.1	98.1	98.1	96.6
GASOLINE LB. PER HR.	42.00	41.16	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0
CONSUMPTION GALLONS	.7616	.7462	.7616	.7616	.7616	.7616	.7616	.7616	.7616	.7616	.7616
LUBRICATION LB. PER HR.	1.43	2.86	4.29	1.43	2.86	2.86	2.86	2.86	2.86	2.86	1.43
OIL CONSUMPTION OIL PER HP.	.014	.029	.044	.014	.029	.029	.029	.029	.029	.029	.014
OIL CONSUMPTION GALLONS	.0019	.0038	.0057	.0019	.0038	.0038	.0038	.0038	.0038	.0038	.0019
OIL CONSUMPTION GALLONS	.0017	.0033	.0050	.0017	.0033	.0033	.0033	.0033	.0033	.0033	.0017
TEMP. OF OIL END OF RUN	110°F	107°F	104°F	105°F	106°F	104°F	96°F				
REMARK REFERENCE	A	B	A	A	A	A	A				

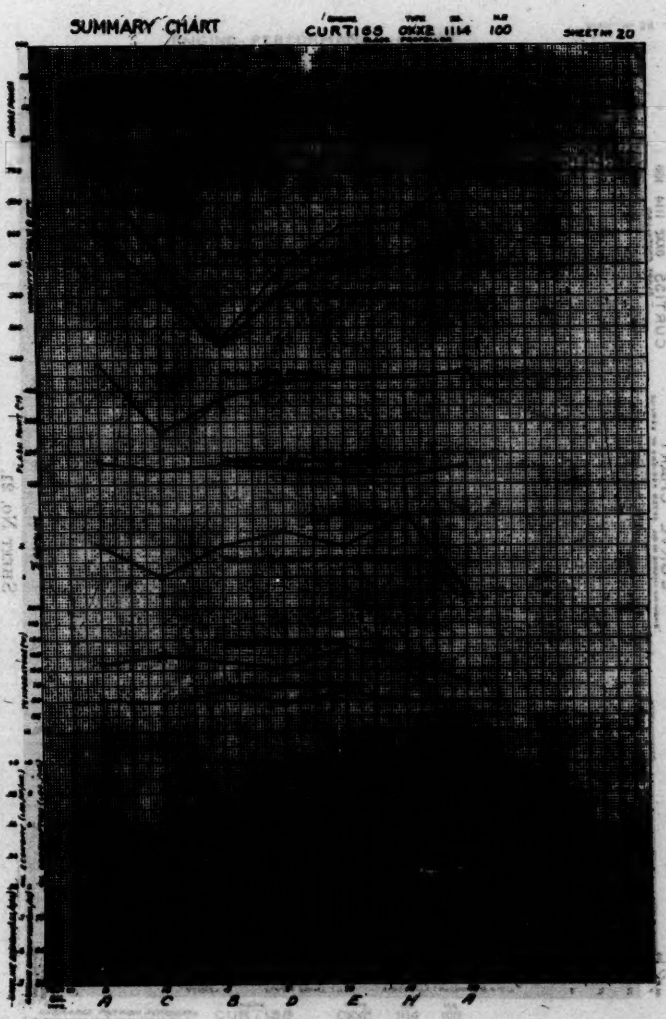
REMARKS:

NOTE A - EXCEPTING TESTS NOS. 10 & 20, FIRST 5 MI. OF RUN WAS RUN UNDER CONDITION OF WIDE OPEN THROTTLE. POWER BASED ON READINGS OF BAROMETER, THERMOMETER, R.P.M., GASOLINE AND OIL CONSUMPTION ARE AVERAGES OF 25 MI. RUN AT APPROXIMATELY 90 % FULL LOAD.

NOTE B - ON TESTS NOS. 10 & 20, ENGINE DID NOT REACH RATED OUT PUT WITH WIDE OPEN THROTTLE. RESULTS ARE AVERAGES OF SHORT RUN.

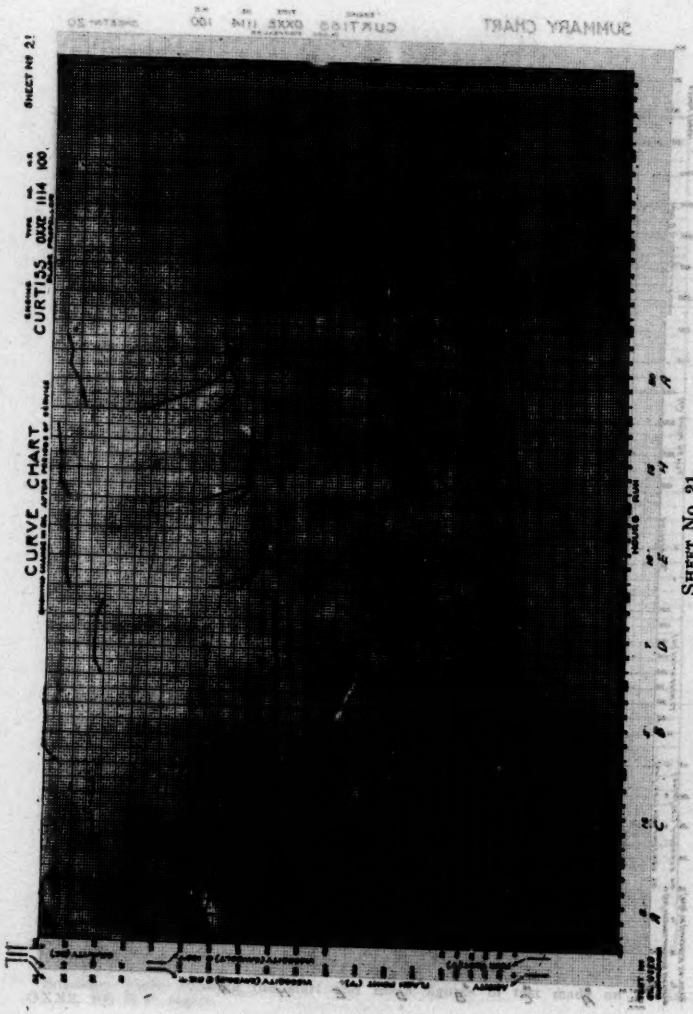
Sheet No. 19.

Summary sheet, showing the start and finish figures of test made on Curtiss OXX2, 100 H.P. engine.



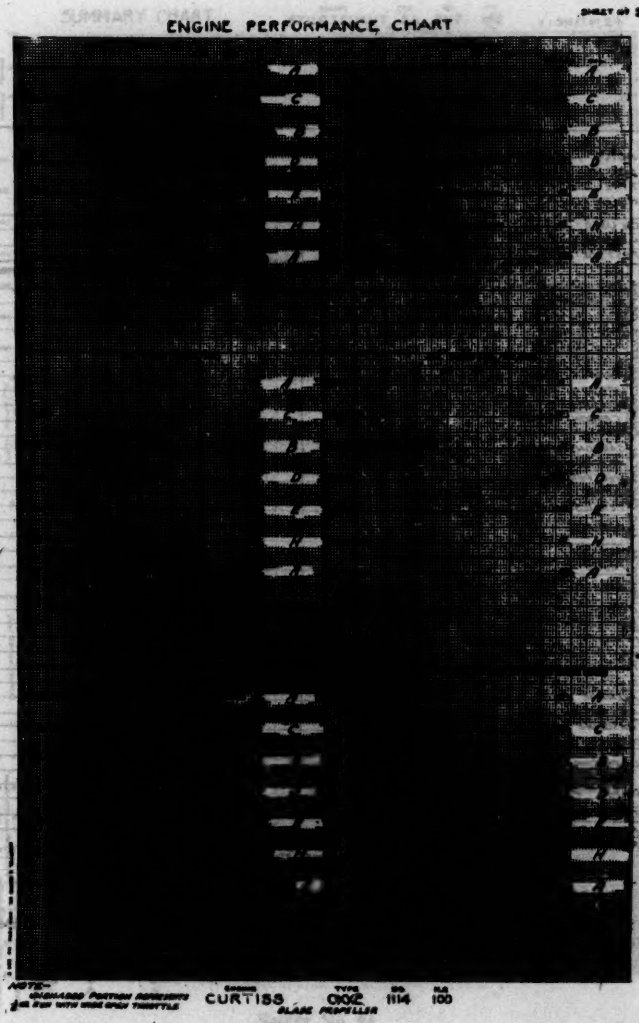
SHEET No. 20.

Summary chart, showing the changes that have taken place in the various oils while operating on the Curtiss OXX2, 100 H.P. engine, and giving the main temperatures and surrounding conditions.



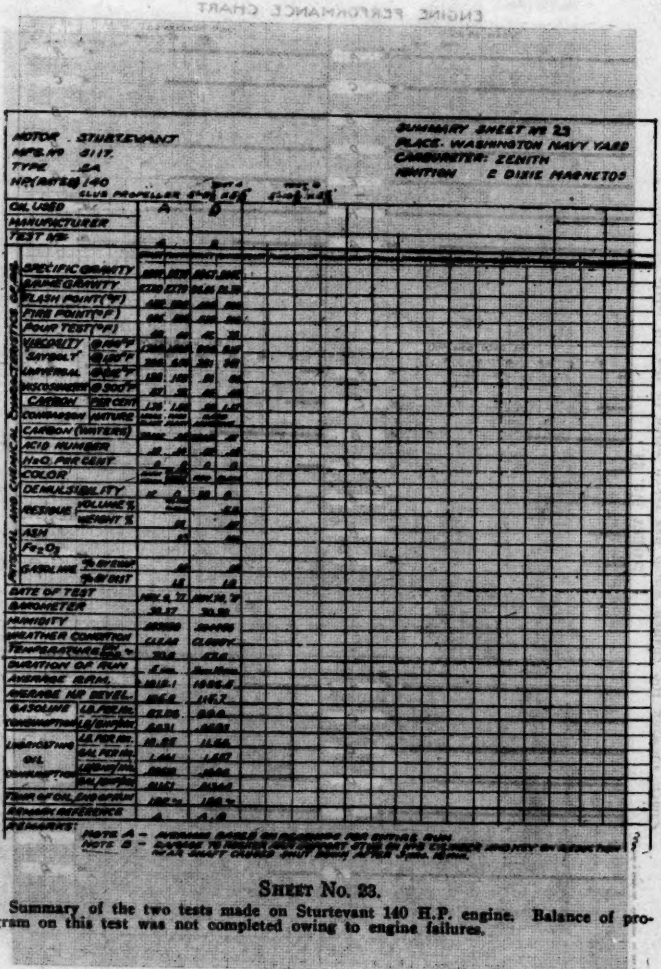
SHEET No. 21.
Chart, showing the change which has taken place in the oil while operating in Curtiss OXX2, 100 H.P. engine.

SHEET No. 20.
Summary chart, showing the changes that have taken place in the various oils while operating on the Curtiss OXX2, 100 H.P. engine, and giving the main temperatures and surrounding conditions.



SHEET No. 22.

Engine performance chart of conditions surrounding the use of the various oils in Curtiss OXX2, 100 H.P. engine.



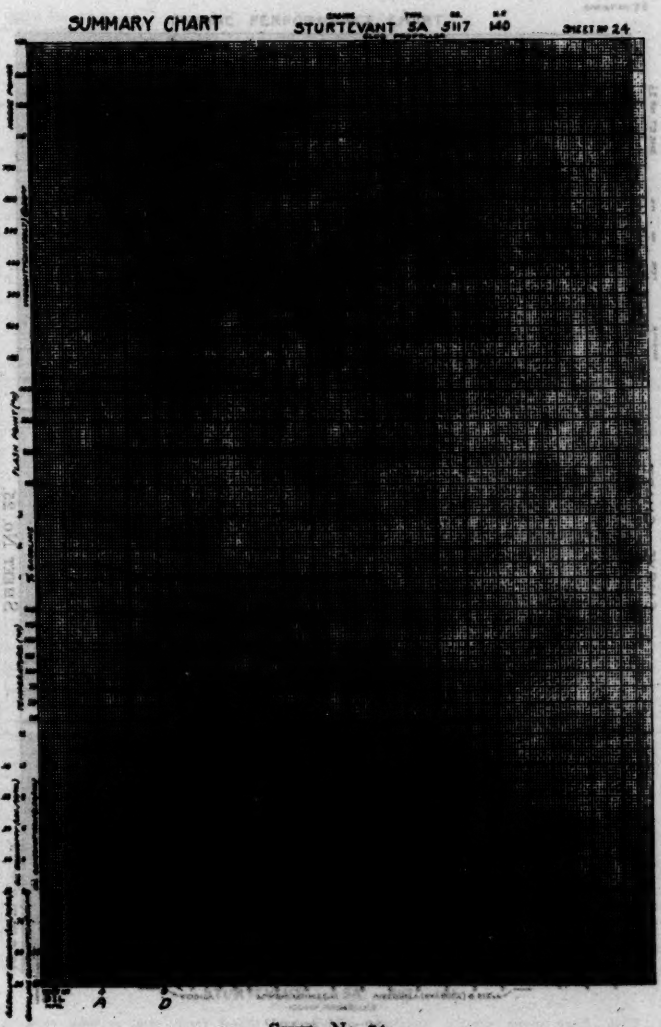
MOTOR . STURTEVANT
MFG. NO 3117.
TYPE .SA
HP(RATED) 140
SUMMARY SHEET NO 23
PLACE. WASHINGTON NAVY YARD
CARBURETER: ZENITH
IGNITION 2 DIXIE MAGNETOS

OIL USED		A	B
MANUFACTURER			
TEST NO		A	B
PHYSICAL AND CHEMICAL CHARACTERISTICS OF OILS	SPECIFIC GRAVITY		
	BAUME GRAVITY		
	FLASH POINT(°F)		
	FIRE POINT(°F)		
	POUR TEST(°F)		
	VISCOSITY @ 100°F		
	SAYBOLT @ 130°F		
	UNIVERSAL @ 100°F		
	VISCOSIMETER @ 300°F		
	CARBON PER CENT		
	COMPARISON MIXTURE		
	CARBON (WATERS)		
	ACID NUMBER		
	H2O. PER CENT.		
	COLOR		
	DEMULSIBILITY		
	RESIDUE VOLUME %		
	RESIDUE WEIGHT %		
	ASH		
	Fe_2O_3		
	GASOLINE % BY VOL		
	% BY WT		
DATE OF TEST			
BAROMETER			
HUMIDITY			
WEATHER CONDITION			
TEMPERATURE(Fahr.)			
DURATION OF RUN			
AVERAGE R.P.M.			
AVERAGE H.P. DEVEL.			
GASOLINE CONSUMPTION	LB. PER HR.		
	LB/H.P./HR.		
LUBRICATING OIL CONSUMPTION	LB. PER HR.		
	GAL. PER HR.		
	LB/H.P./HR.		
	GAL/H.P./HR.		
TEMP OF OIL AND WATER			
CARBON DEPOSITS			
REMARKS			

NOTE A - AVERAGE BASED ON READINGS FOR ENTIRE RUN
NOTE B - [illegible]

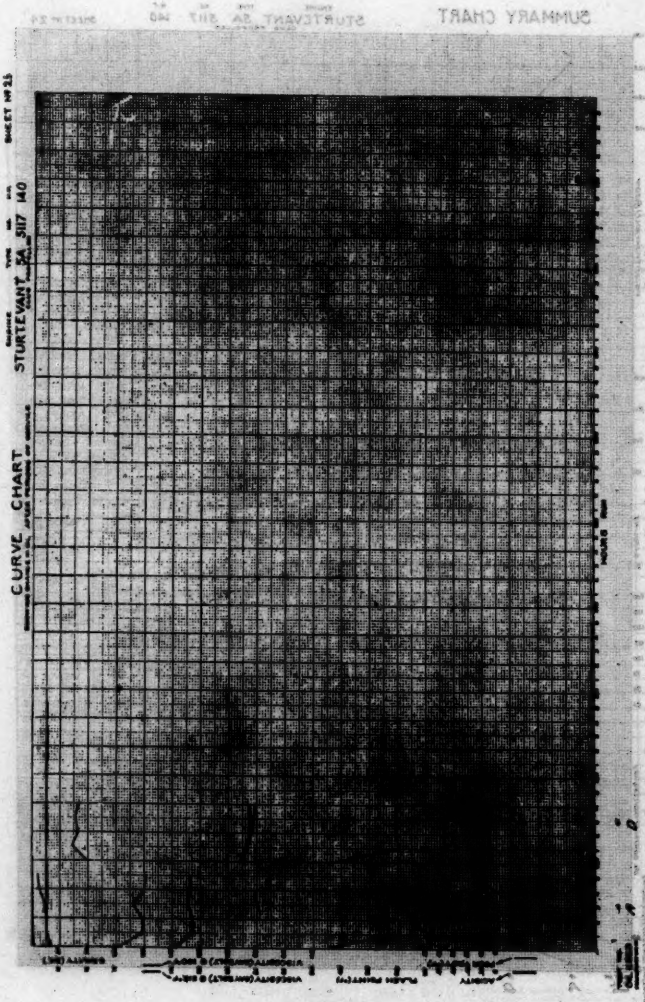
Sheet No. 23.

Summary of the two tests made on Sturtevant 140 H.P. engine. Balance of program on this test was not completed owing to engine failures.



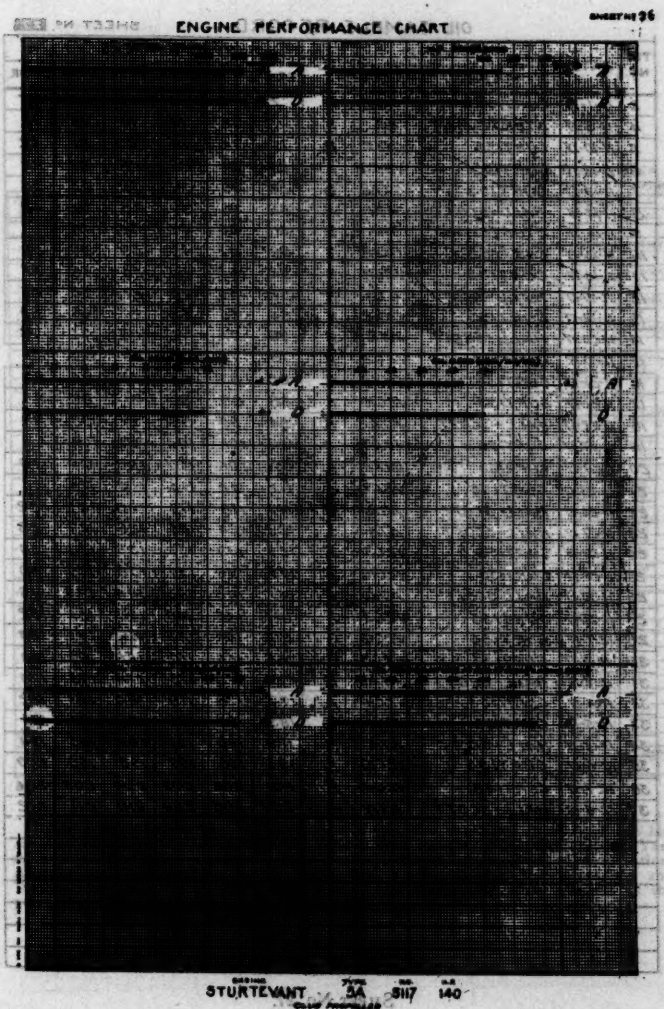
SHEET No. 24.

Summary chart of the main conditions in the Sturtevant 140 H.P. engine test, showing the change in the oil while in the engine.



SHEET No. 25.

Chart showing the change in the oil in two tests on Sturtevant 140 H.P. engine.



SHEET No. 26.

Engine performance chart, showing the conditions during the two tests on Sturtevant 140 H.P. engine.

OIL SAMPLE RECORD

SHEET Nº 27

TEST NO.	DATE	ENGINE		OIL	SAMPLE NUMBERS					
		MAKE	TYPE		NEW	1ST HR	2ND HR	3RD HR	4TH HR	5TH HR.
2	11-1-17	CURTISS	OXXE	A	2	3	4	5	6	7
4	11-9-17	STURTEVANT	5A	A	11	12	13	14	15	16
5	11-10-17	CURTISS	OXXE	B	17	18	19	20	21	22
6	11-12-17	CURTISS	V2C3	A	23	24	25	26	27	28
7	11-13-17	CURTISS	OXXE	D	29	30	31	32	33	34
8	11-14-17	HALL-SCOTT	A7A	A	35	36	37	38	39	40
9	11-14-17	STURTEVANT	5A	D	41	42	43	44	45	
10	11-15-17	CURTISS	OXXE	E	46	47	48	49	50	51
11	11-16-17	CURTISS	V2C3	E	52	53	54	55	56	57
12	11-17-17	HALL-SCOTT	A7A	E	58	59	60	61	62	63
13	11-19-17	CURTISS	OXXE	H	64	65	66	67	68	69
14	11-20-17	HALL-SCOTT	A7A	H	70	71	72	73	74	75
15	11-20-17	CURTISS	V2C3	H	76	77	78	79	80	81
16	11-21-17	CURTISS	OXX2	C	82	83	84	85	86	87
17	11-21-17	CURTISS	V2C10	K	88	89	90	91	92	93
18	11-22-17	HALL-SCOTT	A7A	K	94	95	96	97	98	99
19	11-22-17	CURTISS	V2C3	J	100	101	102	103	104	
20	11-23-17	CURTISS	OXX2	A	105	106	107	108	109	110
21	11-23-17	CURTISS	V2C10	J	111	112	113	114	115	116
22	11-24-17	HALL-SCOTT	A7A	J	117	118	119	120	121	122
23	11-27-17	HALL-SCOTT	A7A	L	123	124	125	126	127	128
24	11-27-17	CURTISS	V2C3	K	129	130	131	132	133	134
25	11-28-17	CURTISS	V2C10	F	135	136	137	138	139	140
26	11-30-17	HALL SCOTT	A7A	F	141	142	143	144	145	146
27	11-30-17	CURTISS	V2C3	F	147	148	149	150	151	152
28	12-1-17	CURTISS	V2C10	G	153	154	155	156	157	158
30	12-3-17	CURTISS	V2C3	G	165	166	167	168	169	170
31	12-3-17	HALL-SCOTT	A7A	D	171	172	173	174	175	176
32	12-4-17	CURTISS	V2C10	A	177	178	179	180	181	182
33	12-5-17	CURTISS	V2C3	D	183	184	185	186	187	188
34	12-5-17	HALL-SCOTT	A7A	M	189	190	191	192	193	194
35	12-6-17	CURTISS	V2C10	D	195	196	197	198	199	200
36	12-7-17	CURTISS	V2C10	E	201	202	203	204	205	206
37	12-8-17	HALL-SCOTT	A7A	E	207	208	209	210	211	212

SHEET No. 27.

This chart gives sample numbers of all oils taken from the various engines, showing date, type and oil.

GASOLINE IN 5th HOUR SAMPLES — CARBON AND SEDIMENT IN 5th HOUR SAMPLE SHEET #28

TEST NO	5th HR SAMPLE NO.	OIL USED	WASH. NAVY YARD LAB. % GASOLINE	ANNAPOLIS LABORATORY % GASOLINE	ROOM TEMP. DU. PER TEST	% CARBON CONRADSON	% CARBON WATERS	% SEDIMENT BY WT	% SEDIMENT BY VOL
		CURTISS-OLXE - NO. 1114							
2	7	A	2.0	2.32	51.8	1.85	0.08	0.57	TOO DARK
5	22	B	2.0	1.88	67.5	0.58	0.09	0.25	14
7	34	D	2.5	2.16	44.2	1.49	0.31	0.57	TOO DARK
10	51	E	2.0	2.30	62.3	1.15	0.04	0.23	14
13	69	M	3.0	3.16	47.1	1.16	0.12	0.10	TOO DARK
16	87	C	1.0	3.48	46.5	1.57	0.29	0.37	12
20	110	A	0.5	2.86	47.5	1.78	0.06	0.064	TOO DARK
		CURTISS - VEC3 NO. 3718							
6	28	A	2.5	2.28	45.6	1.97	0.13	0.57	TOO DARK
11	57	E	2.5	3.66	53.0	1.41	0.13	0.48	24
15	81	M	1.5	3.75	51.8	1.38	0.20	0.34	26
19	104	J	2.5	2.80	58.2	1.00	1.56	0.59	17
24	134	M	0.8	4.60	35.5	4.78	2.46	1.18	TOO DARK
27	152	F	1.75	3.25	41.8	2.13	1.54	0.95	"
30	170	G	0.51	2.79	43.4	1.85	0.31	0.65	++
33	188	D	0.32	2.80	39.9	1.82	0.38	0.62	30
		CURTISS - V2C10 - NO. 3799							
17	93	E	0.25	1.42	52.0	1.00	1.46	0.37	20
21	116	J	1.5	0.89	47.9	0.80	1.49	0.61	22
25	140	F	0.5	1.35	37.3	1.84	1.21	0.53	22
28	158	G	1.2	1.52	50.3	1.44	0.20	0.51	28
32	182	A	1.75	1.36	42.3	2.05	0.08	0.25	24
35	200	D	1.95	1.99	43.3	2.30	0.34	0.47	28
36	206	E	2.2	1.46	35.5	1.33	0.07	0.27	14
		HALL-SCOTT A7A-NO 3012							
3	40	A	0.5	0.49	66.3	2.48	0.09	0.37	12
12	63	E	1.0	0.91	58.0	1.30	0.09	0.43	28
14	75	M	1.5	1.12	59.3	1.46	0.23	0.35	22
18	99	K	0.25	1.20	65.4	1.40	1.02	0.71	36
22	122	J	1.5	0.77	43.5	1.12	1.56	0.72	27
23	128	L	1.7	1.38	40.2	2.51	1.19	0.82	30
26	146	B	1.5	1.00	51.1	2.01	0.96	0.66	20
31	176	D	0.53	1.08	46.5	1.55	0.28	0.49	24
34	194	M	1.2	0.86	52.7	2.10	0.10	0.36	32
37	212	E	0.5	1.97	55.2	1.67	0.10	0.32	15
		STURTEVANT - SA - NO 5118				5117			
4	16	A	1.5	0.60	73.1	1.58	0.05	0.07	TOO DARK
9	45	D	1.0	0.85	68.8	1.85	0.07	0.07	38

Sheet No. 28.

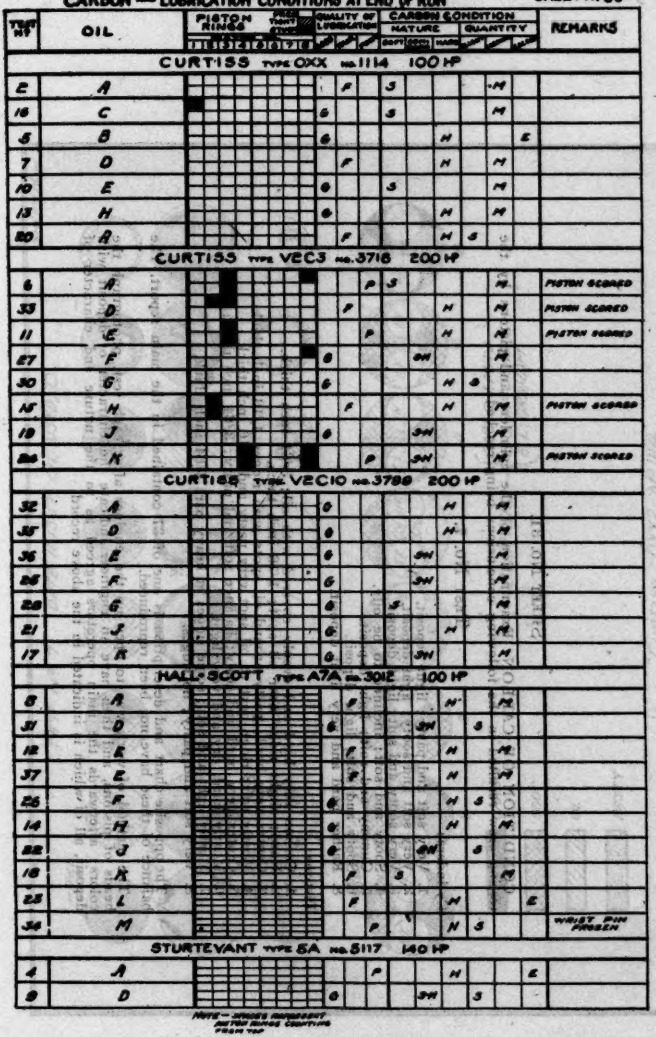
Table giving the readings of percentage of gasoline contained in each of the last samples of entire series of tests as shown first by the Washington Navy Yard method of distillation and then the Annapolis laboratory method of evaporation. Average room temperature during engine test is also shown. The Conradson and Waters percentage of carbon in the fifth or last sample are given as well as the percentage of sediment by weight and volume.

OIL CONSUMPTION RECORD — SHEET Nº 29

TEST NO.	OIL USED	INITIAL CHARGE	AMT ADDED	MEASURED OUT AFTER ENGINE	CONSUMPTION (Lbs) TOTAL	PER HR.	PER BHP/HR	GASOLINE LBS. PER BHP/HR.	H.R. DEVELOPED
		CURTISS OXX2 Nº 1114			100 HP	1400 R.P.M.			
2	A	15.4	8.90	17.15	7.15	1.43	.0155	.7316	91.6
5	B	18.35	33.10	17.60	33.65	6.73	.0714	.7041	89.2
7	D	18.6	0	9.85	8.75	1.75	.0184	.6702	94.3
10	E	18.2	11.20	18.10	11.30	2.26	.0240	.7740	90.1
13	H	16.85	15.10	18.80	13.15	2.63	.0284	.6924	91.8
20	A	16.40	11.10	21.60	7.90	1.89	.0229	.8572	99.8
16	C	19.15	7.55	15.20	11.20	2.24	.0243	.7183	92.1
		CURTISS V2 C3 Nº 3718			200 HP	1400 R.P.M.			
6	A	38.40	16.60	33.2	20.8	4.16	.0257	.8330	163.3
11	E	39.50	21.3	29.75	31.05	6.21	.0388	.9720	172.1
15	H	39.85	18.3	32.65	25.5	5.10	.0289	.7944	178.1
19	J (4 min)	41.60	30.05	36.98	34.07	8.76	.0494	.6611	177.4
24	K	33.70	39.85	40.85	32.20	6.84	.0388	.6965	175.2
27	F	41.85	25.85	32.90	35.06	7.01	.0421	.8234	166.6
30	G	44.22	22.20	32.85	33.47	6.69	.0370	.6618	180.7
33	D	41.0	35.05	37.65	38.20	7.64	.0425	.6357	179.3
		CURTISS V2 C10 Nº 3799			200 HP	1400 R.P.M.			
17	K	36.60	41.80	27.15	48.65	9.73	.0560	.6638	175.3
21	J	37.90	49.80	27.30	60.10	12.02	.0648	.6516	185.1
26	F	44.75	26.15	34.85	36.40	7.08	.0408	.6929	178.8
28	G	43.10	23.00	33.80	32.30	6.84	.0386	.6702	184.4
32	A	42.20	18.60	38.65	23.15	4.63	.0255	.6778	181.8
35	D	44.75	26.10	35.67	32.18	6.44	.0413	.6951	170.3
36	E	41.40	24.8	37.5	28.70	5.75	.0321	.6771	178.9
		HALL-SCOTT A7A Nº 3012			100 HP	1400 R.P.M.			
8	A	16.60	17.70	17.85	16.35	3.27	.0363	.6544	89.1
12	E	19.10	15.75	17.05	16.80	3.36	.0361	.7311	92.4
14	H	17.80	16.85	13.40	21.25	4.25	.0456	.5918	92.2
18	K	15.45	18.80	12.00	23.25	4.65	.0513	.5230	90.8
22	J	12.60	25.90	12.30	26.10	5.22	.0550	.5958	94.4
23	L	15.00	19.65	11.90	21.95	4.39	.0446	.6090	98.5
26	F	18.55	20.30	17.25	21.60	4.32	.0455	.5718	94.1
31	D	24.20	19.70	20.00	23.90	4.78	.0505	.5543	93.7
34	M	21.80	20.80	24.85	17.25	3.45	.0383	.6042	93.4
37	E	18.70	18.10	22.95	14.85	2.98	.0321	.5764	94.4
		STURTEVANT BA Nº 5117			140 HP	2000 R.P.M.			
4	A	20.95	60.20	26.90	54.25	10.85	.0860	.6931	126.2
9	D (3 hr. run)	10.05	63.05	36.25	36.85	11.64	.1006	.6693	115.7

SHEET No. 29.

Oil and gasoline consumption record for the entire series of tests.



Sheet No. 30.

This is the final and last analytical sheet of the entire test, containing in a reduced form all of the necessary data taken from the practical observations of the corps of experts. The data shown on this sheet gave a picture of the mechanical and lubricating conditions of each of the engines after test, and had a very considerable bearing on the final conclusions reached after a study of all of the data.

SHEET No. 31.

CONDITION OF CARBON: Examination of the cylinders and pistons by the testing crew resulted in the following conclusions being reached:

TEST No. 7.

Cylinders:

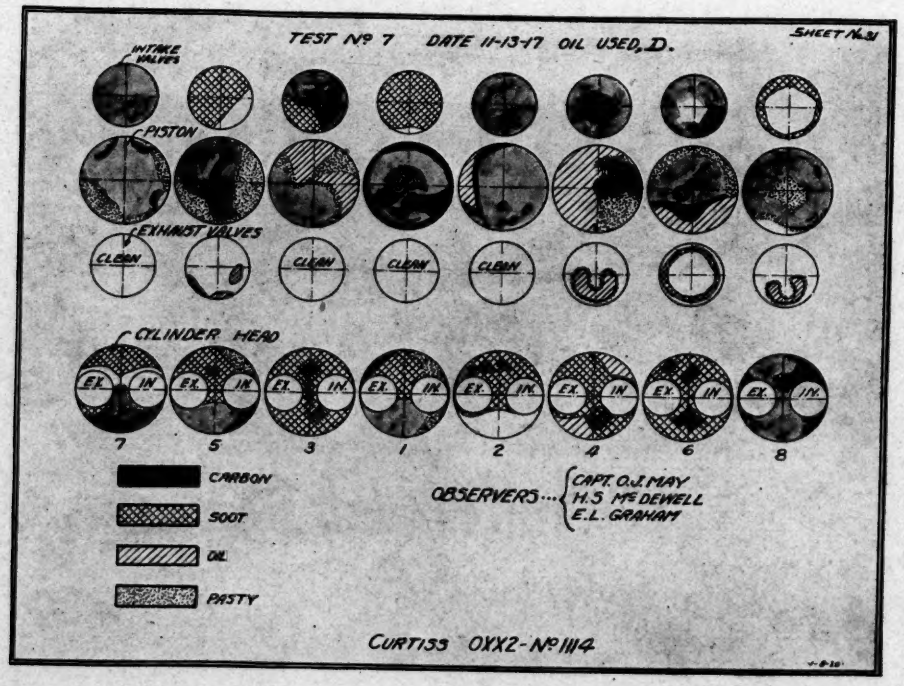
1. Very soft and pasty; light deposit.
2. Very soft and sooty; light deposit.
3. Very sooty and soft; light deposit.
4. Sooty and soft; inclined to be oily.
5. Gummy and soft; light deposit.
6. Sooty and soft; light deposit.
8. Rather hard and very light deposit.

Pistons:

1. Carbon very hard and evenly covered with oil; 3/64 inch thick.
2. Hard; slight ridge near oil spot; 1/16 inch thick.
3. Center very hard; pasty around oil spots with ridges 1/16 inch thick.
4. Mostly soft; ridge next to oil spot very pasty and 1/16 inch thick.
5. Center very hard and scaly; balance soft and pasty; 3/64 inch thick.
6. Mostly hard, dry and very light.
7. Mostly light and soft; some ridges at heavy part 3/64 inch thick.
8. Very soft and pasty; no ridges.

The opposite chart and description is one of 37 contained in the main report. The balance of these have not been reproduced.

The method of work was to open up the engines after each test, photograph the heads of pistons, and then have an engineer indicate the character of deposit with colors; afterwards the main operators agreed as to the nature and character of deposit, all of which is indicated in the above record.


TEST Nº 7 DATE 11-13-17 OIL USED, D.
SHEET No. 31
INTAKE VALVES
PISTON
EXHAUST VALVES
CLEAN
CLEAN
CLEAN
CLEAN
CLEAN
CYLINDER HEAD
EX. IN.
EX. IN.
EX. IN.
EX. IN.
EX. IN.
EX. IN.
EX. IN.
EX. IN.
7 5 3 1 2 4 6 8
CARBON
SOOT
OIL
PASTY
OBSERVERS... CAPT. O.J. MAY
H.S. Mc DEWELL
E.L. GRAHAM
CURTISS OXX2 - Nº 1114

AMERICAN SOCIETY OF NAVAL ENGINEERS

U. S. S. *IDAHO*.

DESCRIPTION AND OFFICIAL TRIALS.

By Henderson B. Gregory, Associate.

Battleship No. 42, the *Idaho*, is one of three vessels authorized by an Act of Congress approved June 30, 1914. The other two vessels of the class are U. S. S. *New Mexico* and U. S. S. *Mississippi*.

The *Idaho* was built by the New York Shipbuilding Corporation, of Camden, N. J., at a price of $7,250,000.00, exclusive of all main armor and the armament.

The contract for the construction of the vessel was signed November 9, 1914, and a little more than two months later, January 20, 1915, the keel of the vessel was laid. On June 30, 1917, the *Idaho* was launched, but owing to the war she was not commissioned until March 29, 1919, preference being given to the construction and completion of the destroyer program, which vessels were sorely needed to combat the German submarine menace.

PRINCIPAL HULL DIMENSIONS.

Length between perpendiculars, feet and inches	600–0
on L.W.L., feet and inches	600–0
over all, feet and inches	624–0
Breadth, extreme, on L.W.L., feet and inches	97–4½
molded, feet and inches	97–0
Depth molded, main deck at side M.S., feet and inches	46–3½
Draught, mean, to L.W.L., feet and inches	30–0
Displacement corresponding, tons	32,000
per inch at L.W.L., tons	100.9
Ratio of length to beam (L.W.L.)	6.16
Coefficient of fineness, block	0.638
midship section	0.979
L.W.L. plane	0.716

GENERAL DESCRIPTION OF HULL.

In profile the *Idaho* closely resembles the *Pennsylvania* class. She has one smoke pipe, four turrets and two masts of the customary cage type, which are provided with spotters' tops, wireless, signal yards, etc. There are eight 36-inch searchlights, four on each mast, and two 24-inch signal searchlights mounted on the signal bridge.

Superstructure Deck and Bridges.—The superstructure deck extends from turret II to frame No. 87. On it are mounted four 5-inch guns, the anti-aircraft guns, stowage of boats, foundry and blacksmith shop, etc. Above the superstructure deck is the bridge deck, where the chart house is located. The navigating bridge is on top of the chart house and just behind the conning tower.

Upper Deck.—This deck extends from the bow aft about half the length of the vessel. Forward are the windlass, two electric deck winches and turrets I and II. Aft of the turrets ten guns of the 5-inch battery are mounted in a casemate, which also contains the officers' and crew's galleys, butcher shop, bakery, etc.

Main Deck.—The main deck is a weather deck abaft the break in upper deck. In the covered portion forward are crew's quarters, and aft on the weather portion are turrets III and IV, two electric deck winches and an electric capstan.

Second Deck.—From forward aft are located chief petty officers' quarters, sick bay, crew's space, junior and warrant officers' quarters, wardroom officers' quarters, and the Captain's quarters.

Third Deck.—On this deck, beginning forward, are stores, windlass machinery, prison, firemen's washrooms, boat crane machinery, radio room, cold-storage rooms, laundry, general workshop and coppersmith's outfit, engineer's tool issuing room, crew's space, provisions, and wardroom staterooms aft.

The first and second platforms and the hold are next below in the order named.

COMPLEMENT.

Provision is made for the following complement:

Commanding officer	1
Executive officer	1
Wardroom officers	24
Junior officers	18
Warrant officers	12
Crew, including chief petty officers	1,327
Marines	75
Total	1,458

BATTERY.

The main battery comprises twelve 14-inch guns, arranged in four three-gun turrets along the center line of the vessel. Turrets I and II are grouped forward on the upper deck, the latter firing over the top of the former, and IV and III are similarly arranged on the main deck aft.

The secondary battery, of fourteen 5-inch rapid-fire guns for torpedo defense, is divided starboard and port as follows: four on superstructure deck and ten within inclosed portion of upper deck.

The 5-inch battery is served by eighteen electric-chain ammunition hoists.

The following smaller guns are also provided:

4 3-inch anti-aircraft guns;
2 1-pounder guns for boats;
2 3-inch field pieces;
2 0.30-caliber machine guns;
12 1-pounder sub-caliber guns.

The torpedo equipment consists of four 6.8-meter by 21-inch submerged torpedo tubes.

SMALL BOATS CARRIED.

The following small boats constitute the ship's regular allowance:

2 50-foot steamers;
1 35-foot motor boat;
2 50-foot motor sailing launches;
2 40-foot motor sailing launches;
1 31-foot racing cutter;
2 30-foot whale boats;
2 20-foot dinghies;
2 14-foot punts.

All boats are carried on the superstructure deck, port and starboard, except the whale boats, which are hung in davits at the ship's side abreast turret III.

Two electrically-operated boat cranes are provided for handling all boats, except the whale boats. Each crane has two operating gears, one for turning and the other for hoisting, driven by 60 and 50 horsepower G. E. motors, respectively.

ANCHOR WINDLASS.

An electric windlass, of the Hyde Windlass Company's design, is located on the upper deck forward, with driving gear below on the first platform. The windlass is driven by two 175-horsepower G. E. motors, through worm gearing and shafting, and so arranged that the wildcats can be operated together or independently of each other.

DECK WINCHES.

Four electric-driven, compound-geared deck winches are provided, two forward on the upper deck and two aft of the main deck, port and starboard, forward of turret III. Three were furnished by the Hyde Windlass Co. and one by S. Flory. All are driven by 45-horsepower G. E. motors.

CAPSTAN.

A Hyde Windlass Co.'s electric capstan is located on the main deck, center line, abaft turret IV, with driving motor below on the third deck. It is compound geared and driven by a 45-horsepower G. E. motor.

STEERING GEAR.

The steering gear is of the Hyde Windlass Company's electric type, operated by a 435-horsepower motor, which is driven by a 290-K.W. motor generator. The Ward-Leonard system of control is provided.

LAUNDRY.

The laundry is located on the third deck, starboard side, midship. It is equipped with the following machinery, all motive power being electricity:

2 Universal presses;
1 Combination ironer;
1 Flatwork ironer;
1 Collar shaper;
2 Extractors;
1 Drying room, 7 drawers;
1 Tumbler dryer;
1 Disinfector;
1 Washer;
1 Ironing table;
1 Soap tank;
1 Starch kettle;
1 2-compartment tub;
3 Truck tubs.

GALLEY OUTFIT.

Officers' Galley.—The officers' galley is equipped with oil-burning range of four sections.

Crew's Galley.—In the crew's galley are installed the following:

1 oil-burning range of eight sections;
4 steam-jacketed copper kettles (80 gallons each);
2 steam-jacketed copper kettles (60 gallons each);
2 coffee urns, 100 gallons each;
1 electrically-driven meat grinder;
1 electrically-driven kitchen and cake machine;
1 hand-operated meat slicer.

The oil for all galley ranges is air atomized; a 10-horsepower, motor-driven, Allis-Chalmers air compressor being provided for the purpose. The capacity of the compressor is 50 cubic feet of free air per minute, at 90 pounds pressure per square inch.

Bakery.—The following equipment is installed in the bakery:

2 No. 1 U. S. Navy standard, electric bake ovens;
2 steam boxes;
2 portable dough troughs;
1 electrically-driven dough-mixing machine;
1 electrically-driven kitchen and cake machine;

Miscellaneous equipment located as noted:

1 electrically-driven potato peeler, in potato-peeler room;
1 electrically-driven dish washer, capacity 6,000 pieces per hour, in general mess pantry;
4 warming ovens, in serving room;
1 electric butter slicer, in general mess issuing room.

GARBAGE PLANT.

For disposal of garbage, one oil-burning incinerator is located on the superstructure deck.

DRAINAGE SYSTEM.

The two fire and bilge pumps in each wing engine room have 5-inch suctions from the after drainage system, which serves compartments aft of number three fire room.

The main circulating pumps are located in the center engine room. They are arranged for pumping on the engine-room bilges in emergencies. There are two bilge connections for the center engine room, and one for each wing engine compartment; each connection is 22 inches diameter.

Each fire room is normally drained by the fire and bilge pump located therein. For extreme emergencies two 10-inch, Morris, electrically-driven, vertical, centrifugal pumps are provided for each fire room, with driving motors, 45-horse-power each, located above on the third deck.

The drainage of compartments forward, except the forward dynamo room and double bottoms beneath, which are drained by the fire-room system, is handled by an independent system, served by a 5-inch Morris, horizontal, motor-driven, centrifugal pump. The driving motor is 30 horsepower.

All the Morris pumps are driven by G. E. motors.

FIRE MAIN.

The fire main is supplied by seven fire and bilge pumps, located in the outboard engine rooms and fire rooms.

The main is entirely below the third deck and extends throughout the machinery spaces in two 8-inch lines, port and starboard. It is cross-connected at the forward and after ends, and in the engine compartments, and supplied by 5-inch connections from the fire and bilge pumps, with cutout valves at the main. Branches to fire plugs, etc., are provided as required.

There is a connection forward to the independent sanitary system for the crew's water closets and washroom. A stop valve is provided where it joins the latter.

SANITARY SYSTEM.

Water for sanitary purposes is supplied from the fire main risers.

Branches, as required, are led to the chief petty officers' washroom and water closets, sick bay, bath, laundry, general

mess pantry, galleys, bakery, firemen's washrooms, junior, warrant and wardroom officers' lavatories and water closets, etc.

Forward there is an independent system for the exclusive use of the crew's washroom and water closets. This system is supplied by two 12-horsepower, 5-inch, Morris, motor-driven, direct-connected, double-inlet, horizontal centrifugal pumps, of about 500 gallons per minute capacity each. G. E. motors drive the pumps. The main is 5 inches in diameter, with the necessary branches to the plumbing fixtures.

FRESH WATER SYSTEM.

The following fresh-water tanks are provided:

	Gallons.
Ship's tanks	68,080
Mess attendants' washroom supply tank	100
Chief petty officers' washroom supply tank	150
Firemen's washroom supply tanks	500
Battle-dressing station supply tanks	250
Laundry tank	200
Crew's washroom tanks	450

The ship's tanks have 2½-inch filling connections from the ship's sides, and also a 2½-inch connection from the distiller main. From these tanks water is pumped through the fresh-water main by means of three 3-inch, Morris, direct-connected, electric-driven, horizontal centrifugal pumps of 200 gallons capacity per minute each, driven by G. E. motors of 12-horsepower each. Branches are led as required from the main to the various lavatories, pantries, etc., and the small gravity tank enumerated above.

REFRIGERATING PLANT.

The ice-machine room is on the second platform, port side, between the engine and fire rooms. The plant consists of the following apparatus:

2 Steam-driven, Roelker, Allen dense air ice machines, each of 3 tons capacity.
1 Brine-circulating pump of the horizontal, motor-driven, centrifugal type, for ice cream freezer.
2 9-can ice-making boxes.
1 Ice cream freezer.
1 Hardening cabinet for ice cream.
2 Scuttle butts.
4 Cold-storage rooms.

The cold-storage compartment is located on the third deck, immediately above the ice-machine room, and consists of four rooms, one each for meat, butter, officers, and the crew, the latter serving also as vestibule. The rooms are heavily insulated and fitted with cooling coils of 1½-inch galvanized iron pipe. The following data is given for the cold-storage compartments:

Compartment.	Room surface, sq. ft.	Cooling surface of coils, sq. ft.	Temperature to be maintained.
Meat room	1,080	462	15°F.
Butter room	201	81	40°F.
Crew's room	267	102	40°F.
Officers' room	395.4	160	40°F.

The cold storage rooms and scuttle butts are cooled by direct circulation of the cold air through the coils therein; the ice-making boxes and the hardening cabinet have brine baths, which are cooled by submerged coils, through which cold air circulates. Brine from the latter is used for freezing ice cream. A small brine circulating pump is provided for the service.

RESERVE FEED TANKS AND CONNECTIONS.

Double-bottom compartments B-1 to B-4, inclusive, are fitted up as reserve feed tanks.

The tanks are filled through a 3½-inch pipe fitted with two 2½-inch hose connections at the ship's sides, port and starboard, and connected to the combined filling and suction manifold in fireroom No. 2.

There is also a 2½-inch filling pipe from the distiller fresh-water main, which is led to the same manifold. From the manifold 4-inch combined filling and suction pipes are led to the bottom of each tank.

There is a 4-inch main between the manifold and the auxiliary-feed pump suctions, so that the auxiliary-feed pumps may draw from any tank. The auxiliary-feed pump in fire room No. 2 is arranged to draw direct from any tank and discharge to any other tank. The reserve feed pump in No. 2 fire room also has a 4-inch suction from the manifold, for drawing water direct from any tank and discharging same to the main feed tanks.

There is also a reserve feed pump in the center engine room, with suction connections from the reserve feed tanks, and discharge connections to the main feed and filter tanks.

VENTILATING SYSTEM.

Artificial ventilation is provided where necessary for all quarters, living spaces, passages, storerooms, magazines, engine rooms, dynamo rooms, evaporator room, etc.

In general air is supplied on the plenum system to the different compartments requiring ventilation. The toilet spaces are also provided with the exhaust system.

The ventilating fans are of the B. F. Sturtevant Company's type, driven by G. E. Co. motors, except for a few minor exceptions.

Heater boxes are fitted in the ventilating ducts to all quarters, crew's space, etc., for heating the incoming air in cold weather; no other heating apparatus being provided for these spaces.

HEATING SYSTEM.

All staterooms and quarters, crew's space, etc., are heated by the thermo-tank ventilating system; heater boxes provided with suitable steam coils are placed in the air duct for heating the air supplied to these compartments. The heater boxes are of the B. F. Sturtevant Company's type. The remaining portions of the vessel, except the turrets, torpedo room and charthouse, which are provided with electric heaters, are heated by the customary pipe-coil steam radiators.

The heating system is divided into two main sections, one forward and one aft. The former takes steam from the auxiliary steam pipe in fire room No. 1, and the latter from the auxiliary steam pipe in the center engine room. Stop and reducing valves are fitted at the branches from the auxiliary steam pipes.

The galley steam is taken off the auxiliary steam line in fire room No. 1; a stop valve and a reducing valve are provided at the connection.

The drains from the heating system and galley are led to suitable traps, which discharge to the feed and filter tanks and condensers.

MAIN ENGINES.

The propelling machinery consists of Parsons turbines, driving four lines of shafting. The turbines are designed to develop 32,000 shaft horsepower, with a steam pressure of 200 pounds gauge at the H.P. turbines, and when making 240 revolutions per minute.

There are six main turbines and two cruising sets, arranged in three separate watertight compartments. The turbines are grouped as follows: One H.P. ahead turbine, and one H.P. astern turbine, immediately abaft same, on each outboard shaft and located in each outboard engine room. One L.P. ahead and astern turbine on each inboard shaft. A cruising turbine is geared to the forward end of each L.P. ahead and

astern turbine. The L.P. turbines and cruising sets are installed in the center engine room. Slip couplings are provided for disconnecting the cruising sets when running at the higher speeds.

The following steaming conditions are provided:

Four shafts in operation.

1. Low cruising speed—Steam to cruising turbines, exhaust through H.P. ahead turbines, to L.P. ahead turbines, into condensers.
2. Medium cruising speed—Steam bypassed to second expansion of cruising turbines, exhaust through H.P. ahead turbines, to L.P. ahead turbines, into condensers.
3. High cruising speed—Steam bypassed to 4th expansion of cruising turbines, exhaust through H.P. ahead turbines, to L.P. ahead turbines, into condensers.
4. Full speed ahead—Steam to H.P. ahead turbines, exhaust through L.P. ahead turbines into condensers.
5. Full speed astern—Steam to H.P. astern turbines, exhaust through L.P. astern turbines into condensers.

Two shafts in operation.

6. Low cruising speed—Steam to cruising turbines, exhaust through L.P. ahead turbines into condensers.
7. Medium cruising speed—Steam bypassed to second expansion of cruising turbines, exhaust through L.P. ahead turbines into condensers.
8. High cruising speed—Steam bypassed to fourth expansion of cruising turbines, exhaust through L.P. ahead turbines into condensers.
9. Cruising speed—Steam to L.P. ahead turbines, exhaust into condensers.
10. Maneuvering—Steam to L.P. ahead or L.P. astern turbines, exhaust into condensers.

Under conditions 1, 2 and 3, auxiliary exhaust may be admitted to the third stage of the H.P. ahead turbines, and, under condition 4, to the first stage of the L.P. ahead turbines.

Ex-pansion.	Diameter of Cylinder Inches.			Length of Cylinder this Diameter. Inches.			Rows of Blade	
	Cruis-ing	Low Press.	High Press.	Cruis-ing.	Low Press.	High Press.	Cruis-ing.	Low Press
1st	23-13/16	135	86-1/4	14-3/4	15	22-1/4	16	8
2nd	24	139	87-1/4	13-7/8	15-3/4	22-7/8	14	8
3rd	24-5/8	144-1/2	88-1/2	18	17-1/4	24-3/8	14	8
4th	24-1/2	152	90-1/2	12-9/16	17-11/16	25-1/8	9	7
5th	25-3/4	152	93	12-7/8	17-11/16	26-1/4	9	7
6th		152	98		19-1/4	32-5/8		7

Ex-pansion.	H.P.Astern Turbine.				
	Diameter of Cylinder Inches.	Length of Cylinder This Dia. Inches.	Rows of Blades.	Length of Blades Inches.	Approx of Bla in each r
1st	86	13-3/8	9	1	1040
2nd	87	12-7/8	9	1-1/8	1052
3rd	88-1/2	12-7/8	9	2-1/4	1070
4th	91	14-1/4	9	3-1/8	1101
Rotor Drums.		Cruising Tu			
Diameter, inches Length, inches		For'd End - 22-13/16, Center - 77-3/8			

Reduction Gear	Parsons Type - Connecting Cruising Turbine & L.P.& Astern Turb.
Coupling	Parsons flexible coupling between cru
Clutch	Flexible jaw and sleeve type, operate

TURBINE DATA.

Ahead Turbines:

Rows of Blades.			Length of Blades.			Cruising.			
s-	Low Press.	High Press.	Cruising	Low Press.	High Press.	Approx. No. of Blades in each row.	Longitudinal Pitch. Inches.	Tip Clearance. Inches.	Approx No. of Blades in ea row
	8	17	1/2	5-1/2	1-1/8	434	7/8	.030	1258
	8	17	13/16	7-1/2	1-5/8	437	15/16	.030	1275
	8	17	1-1/8	10-1/4	2-1/4	898	1-1/4	.035	1021
	7	17	1-1/2	14	3-1/4	896	1-5/16	.035	917
	7	17	2-1/8	14	4-1/2	511	1-3/8	.040	874
	7	17		14	7				807

ine.				L.P.Astern Turbi				
	Approx.No. of Blades in each row.	Longitudinal Pitch Inches.	Tip Clearance. Inches.	Diameter of Cylinder Inches.	Length of Cylinder This Dia. Inches.	Rows of Blades.	Length of Blades Inches.	Ap of
	1040	1-3/8	.050	100	15-3/4	7	5	
	1052	1-3/8	.055	104	15-5/8	7	7	
	1070	1-3/8	.060	104	15-7/8	6	7	
	1101	1-1/2	.060	104	15-3/4	6	7	

ising Turbine.	H.P.Ahead	L.P.Ahead	H.P.Astern
enter - 22-3/8. Aft. End - 21-1/2	84	124	84
77-3/8	155	102-3/8	88-7/8

Reduction Gear Data.

		No.of Teeth	Pitch Dia.	Circ. Pitch	Spiral Angle	Outside Dia.	Ratio
	Pinion	89	7.53172"	.815919	44°.23.7'	7.77172"	1 to
rn Turb.	Wheel	579	98.43179"	.815919		98.67179"	13.069

ween cruising turbine rotor and reduction gear pinion shaft.
operated through handwheel, screw spindle and nut with bell crank.

TURBINE DATA.

Ahead Turbines.

...ws of ...des.		Length of Blades.			Cruising.			Low Pres...	
...w ...ss.	High Press.	Cruising	Low Press.	High Press.	Approx. No. of Blades in each row.	Longitudinal Pitch. Inches.	Tip Clearance. Inches.	Approx. No. of Blades, in each row	Longit dinal Pitch Inches
	17	1/2	5-1/2	1-1/8	434	7/8	.030	1238	1-3/4
	17	13/16	7-1/2	1-5/8	437	15/16	.030	1275	1-7/8
	17	1-1/8	10-1/4	2-1/4	398	1-1/4	.035	1021	2-1/1
	17	1-1/2	14	3-1/4	296	1-5/16	.035	917	2-3/8
	17	2-1/8	14	4-1/2	311	1-3/8	.040	874	2-9/1
	17		14	7				807	2-3/4

			L.P.Astern Turbine.				
...ox.No. ...lades ...n ... row.	Longitudinal Pitch Inches.	Tip Clearance. Inches.	Diameter of Cylinder Inches.	Length of Cylinder This Dia. Inches.	Rows of Blades.	Length of Blades Inches.	Approx.No. of Blades in each row.
40	1-3/8	.050	100	13-3/4	7	5	917
52	1-3/8	.055	104	15-5/8	7	7	735
70	1-3/8	.060	104	13-7/8	6	7	693
01	1-1/2	.060	104	15-3/4	6	7	552

Turbine.	H.P.Ahead	L.P.Ahead	H.P.Astern	L.P.Ast...
- 22-3/8. Aft. End - 21-1/2	84	124	84	90
	155	102-3/8	58-7/8	61-1...

Reduction Gear Data.

		No.of Teeth	Pitch Dia.	Circ. Pitch	Spiral Angle	Outside Dia.	Ratio	Be... No.	Di...
.	Pinion	39	7.53172"	.815919	44°.23.7'	7.77172"	1 to	3	5
b.	Wheel	379	98.43179"	.815919		98.67179"	13.069	2	12

...ruising turbine rotor and reduction gear pinion shaft.
...ted through handwheel, screw spindle and nut with bell crank.

Low Pressure.			High Pressure.		
. h	Longitu-dinal Pitch. Inches.	Tip Clear-ance. Inches.	Approx. No. of Blades in each row.	Longitu-dinal Pitch. Inches.	Tip Clear-ance. Inches.
	1-3/4	.075	1043	1-1/4	.045
	1-7/8	.080	1055	1-5/16	.050
	2-1/16	.090	1070	1-3/8	.055
	2-3/8	.110	1095	1-7/16	.060
	2-9/16	.110	1125	1-1/2	.065
	2-3/4	.110	899	1-7/8	.070

ge.		
prox.No. Blades in ch row.	Longitu-dinal Pitch Inches.	Tip Clear-ance. Inches.
917	1-13/16	.070
735	2-1/8	.090
693	2-5/16	.090
552	2-5/8	.090

L.P.Astern
90
61-1/2

Bearings.		
No.	Dia.	Length.
3	5"	2 - 5-3/4"
		1 - 10"
2	12"	12-1/4"

Turbine Data.

	Cruising	H.P. Ahead	H.P. Astern	L.P.& Astern
Rotor bearings:				
Length, white metal, inches	7½	22½	15½	32
total, inches	10	28	17	39½
Diam., white metal, inches	5	16	16	20
brass, inches	5.03	16.03	16.03	20.03
Thrust collars:				
Number	15	15	none	9
Thickness, inches	3/8	13/16	"	1
Space between, inches	1/2	1-1/8	"	1-1/8
Outside diameter, inches	6	22	"	24
Inside " "	5½	16½	"	17
Thrust rings:				
Number	24	30	none	16
In contact, top	0 For'd. 12 Aft.	0 Ahd. 14 Ast.	"	8 Ahd. 8 Ast.
bottom	12 " 0 "	15 " 0 "	"	8 " 8 "
Inside diameter, inches	5½	16½	"	17½
Effective surface, top, sq. ins.	98.874	947.83	"	1460.88
bottom, sq. ins.	98.874	1015.53	"	1460.88
Rotors:				
Length, including drums, rotor ends and wheels, feet and inches	13 - 6-13/16	26 - 11-5/16	13 - 11-3/4	30 - 8-1/8
Diam. rotor ends, at bearings, "	5	16	16	20
Bore of rotor ends, inches	none	9	9	10½ For'd. 11 Aft.

PLATE II.

The turbines are of the characteristic Parsons design throughout, hence, a detailed description is both unnecessary and beyond the scope of this article.

The principal turbine data are given in Plates I and II.

SHAFTING AND BEARINGS.

There are four lines of shafting, each composed of the following number of separate sections, all rigidly coupled together:

	Inboard shafts.	Outboard shafts.
Line shaft	3	2
Stern-tube shaft	1	1
Propeller shaft	1	1

Line Shafts.—These shafts are forged steel, hollow, with disc couplings at either end, and carried by suitable steady bearings.

Stern-Tube Shafts.—The stern-tube shafts are covered with a composition casing within the stern tubes and at the stern tube bearings. They are forged steel, hollow, secured to the line shafts at inboard end by special disc couplings, and to the propeller shafts at outboard end by sleeve couplings. Two lignum vitæ lined bearings are provided for each stern tube shaft.

Propeller Shafts.—Each propeller shaft is carried by one lignum vitæ lined strut bearing. The shafts are forged steel, hollow, taper turned at after end to suit the propeller hub, and composition bushed at the bearings.

Inboard Coupling.—Each inboard coupling consists of a forged steel sleeve secured to the stern-tube shaft by four keys, the end of the shaft being slightly upset for reception of the sleeve. The shaft is prevented from pulling out of the sleeve when backing by two segments fitting a transverse slot in the forward end of the sleeve, and shouldered into a groove turned in the end of the shaft. The sleeve and segments are through bolted to the line shaft coupling by eight fitted bolts.

Outboard Coupling.—Each outboard coupling is of forged steel, solid-sleeve type, taper bored for reception of shafts, and secured to each shaft by two feather keys and one cross key.

SHAFT DATA.

Line shafts, forward, outboard, length, feet and inches	30–01 1/8
after, outboard, length, feet and inches	23–08 9/16
inboard, length, feet and inches	30–01 1/8
diameter, inches	14
at bearings	14 1/4
axial hole, inches	9
Stern-tube shafts, length, feet and inches	41–00 5/16
diameter, inches	14 3/8
axial hole, inches	9
Propeller shafts, length, feet and inches	35–01 1/2
diameter, inches	14 3/8
axial hole, inches	9
Coupling discs, diameter, inches	25
thickness, inches	3 1/2
Inboard coupling, diameter of sleeve outside, inches	25
inside, inches	15 7/8
length of sleeve, inches	13
Coupling bolts, number each coupling	8
diameter (taper) at face of coupling, inches	2 3/4
Outboard couplings, length of sleeve, inches	55 1/2
diameter of sleeve, inches	20

BEARING DATA.

Line-shaft bearings (white-metal lined):	
diameter, inches	14 1/4
length, inches	23 3/4
Stern-tube bearings (lignum vitæ lined):	
forward bearing, diameter, inches	16 11/16
length, inches	48
after bearings, diameter, inches	16 3/4
length, inches	60
Strut bearings (lignum vitæ lined):	
diameter, inches	16 13/16
length, inches	72

TURNING GEAR.

Each line of main shafting is provided with a motor-driven, reversible turning gear. The motors are 15 horsepower each.

Each gear is so arranged that it can be operated by hand, a long ratchet wrench being provided for that purpose.

PROPELLERS.

There are four three-bladed propellers, with the blades cast solid with the hubs. The starboard propellers are right-hand and the port propellers are left-hand; all propellers turn outboard when driving the vessel ahead. They are of manganese bronze and the hubs are taper bored to fit the shafts, to which they are secured by two keys and locked nut on the end of each shaft. The blades are machined true to pitch, and polished all over, including the hubs.

PROPELLER DATA.

Diameter of propeller, feet and inches	12–4
hub, feet and inches	2–2¾
Pitch, feet and inches	10–4.44
Ratio of diameter to pitch	0.841
Area, projected, square feet	52.56
helicoidal, square feet	58.5
disc, square feet	119.46
Ratio, projected to disc area	0.44
helicoidal to disc area	0.49
Heighth of lower tip of blade above keel, inches, inboard	8⅝
outboard	26⅝
Immersion of upper tip of blade, feet and inches, inboard	17–7.175
outboard	16–0

MAIN CONDENSING APPARATUS.

The main condensing outfit consists of the usual surface condensers, each fitted with a Parsons vacuum augmenter, working in conjunction with an air pump.

Main Condensers.—There are two cylindrical main condensers, one for each L.P. turbine. They are installed abreast in the after end of the center engine room. The tubes are straight, rolled into the tube sheets at one end and gland packed at the other end. The condensers are of the following principal dimensions:

Inside diameter, feet and inches	10–2
Thickness of shell (steel), inch	0½
Length between tube sheets, feet and inches	11–3
Thickness of tube sheets, inches	1¼
Tubes, number	8,706
diameter, outside, inch	0⅝
thickness, inch	0.065
Cooling surface, square feet	16,023
Size of main exhaust nozzles, inches	84×122
Diameter, air-pump suction, inches	13½
augmenter suction, inches	16
auxiliary exhaust nozzle, inches	10
circulating-water inlet (2), inches	21
outlet, inches	30

Augmenter Condensers.—Each main condenser is provided with an augmenter condenser, located beneath the main unit. They are of the bent tube type, and cylindrical in cross-section. The tubes are expanded into both tube sheets. The principal dimensions are as follows:

Inside diameter, feet and inches	2–3 1/2
Thickness of shell (composition), inch	5/16
Length between tube sheets, feet and inches	4–4
Thickness of tube sheets, inch	1
Tubes, number	440
diameter, outside, inch	5/8
thickness, inch	0.065
Cooling surface, square feet	312.5
Diameter, air pump suction, inches	12 1/2
dry suction, inches	14
circulating water inlet and outlet, inches	6

Main Air Pumps.—The main air pumps, one for each main condenser, are of the Warren, twin-beam, vertical, single-acting type, with steam cylinders 13 inches in diameter, air cylinders 36 inches in diameter, and a common stroke of 27 inches. They are located inboard and below the main condensers.

Main Circulating Pumps.—Circulating water for each main condenser is supplied by a horizontal, bi-rotor, turbine-driven,

direct-connected, double-inlet, centrifugal pump located in the center engine room. They are also arranged for pumping on the engine-room bilges in emergencies. The pumps and turbines are of the following principal characteristics:

Make of pump	Worthington, Type B-1, Volute
Capacity, gallons, per minute	20,200
Diameter, impellers (2), inches	15½
sea suctions (2), inches	22
bilge suction, inches	22
discharges (2), inches	20
Horsepower of turbine	307
R.p.m.	1,350
Make of turbine	Terry Steam Turbine Co.

FORCED LUBRICATION SYSTEM.

There is a complete lubrication system for each side of the ship. The two systems are cross-connected. Cut-out valves are fitted in the cross-connections.

Each system consists of the following principal equipment, located in the center engine room:

2 6-inch × 8-inch × 12-inch, Warren, vertical, piston, double-acting, single, oil pumps.

1 7-inch × 8-inch × 12-inch, Warren, vertical, piston, double-acting, single, oil cooler circulating pump.

2 No. 7 Schutte-Koerting, Type Z, oil coolers, of 212 square feet cooling surface each.

2 Lubricating oil drain tanks of 1,000 gallons combined capacity.

The lubricating-oil pumps draw oil from the drain tanks and discharge same through the oil coolers, thence, via the lubrication main and its branches, to the bearings. The oil coolers can be by-passed if so desired. The oil from the bearings is led back to the drain tanks through drain lines, thus completing the cycle, which is indefinitely repeated. Cut-out valves are provided as necessary for isolating units not in operation.

A thermometer is fitted at each oil-cooler inlet and outlet, and also at each bearing outlet.

A 4½-inch × 5-inch × 6-inch, Warren, vertical, piston, double-acting, single, oil drain pump is provided common to both systems. It has a suction from the drain tanks and discharges to the oil treating tanks and oil storage tanks, mentioned elsewhere.

Cooling water for the oil coolers is supplied in emergencies from the fire and bilge pumps or the main condenser circulating pumps, in addition to the regular oil cooler circulating pumps.

Reserve lubricating oil is carried in two storage tanks of 3,000 gallons combined capacity, located in the center engine room. These tanks are provided with deck-filling connections and are arranged for readily replenishing the forced-lubrication system.

Two 500-gallon lubricating-oil treating tanks, fitted with steam heating coils, are also located in the center engine room. The forced-lubrication pumps are arranged to pump the oil from the system into these tanks when it requires cleansing. The tanks drain by gravity to the drain tanks.

WATER SERVICE SYSTEM.

The water service for the main turbines, thrust and spring bearings, stern tubes, main circulating and main feed pump bearings, is supplied from connections taken off the main circulating pumps, fire and bilge pumps and oil-cooler circulating pumps discharges.

Branches, controlled by separate valves or cocks, are led to the spring bearings and auxiliaries noted above. Hose valves are provided at convenient locations. No direct connections are made to the main turbine bearings and thrust blocks, nor to the cruising turbine and reduction gear bearings.

The returns are led to the 11-inch overboard discharge in the center engine room.

FIRE AND BILGE PUMPS.

There are seven fire and bilge pumps, two located in each outboard engine room and one in each fire room. They have suctions from the sea and the drainage systems, and discharge to the fire and flushing mains and overboard. The engine-room pumps also discharge to the oil coolers and water service.

The pumps are of the following characteristics:

Type—Warren, vertical, piston, double-acting, single.
Size—12 inches by 10 inches by 18 inches.
Diameter of suction and discharge, 5 inches.

BOILERS.

There are nine Babcock & Wilcox water-tube boilers, arranged three abreast in three separate watertight compartments.

The boilers have a total heating surface of 55,458 square feet, and are designed to operate the entire machinery plant at full power, with an average air pressure in the ash pits of not more than 6 inches of water. They are equipped for burning fuel oil.

Uptakes of the usual design are provided, all uniting into a common smoke pipe at the main deck. The smoke pipe is 13 feet 9 inches inside diameter, and 92 feet 10 inches high above the base of the boilers. It is divided into three sections of 46.59 square feet area each.

BOILER DATA.

Number	9
Pressure, working, pounds per square inch	250
test, pounds per square inch.....water, 375; steam	300
Height to top, external, feet and inches	15–1 11/16
Length on floor, feet and inches	9–0 1/4
Width on floor, feet and inches	17–3 5/8
Drum, diameter, inside, inches	42
length, feet and inches	18–0 1/4
thickness, inch	11/16
Number of tube headers, each boiler	56

Distance between headers, feet and inches	9–00
Number of tubes, each boiler:	
2-inch generating tubes, 134 mils. thick	1,210
4-inch generating tubes, 165 mils. thick	28
Number of furnaces, each boiler	1
Furnace volume, each boiler, cubic feet	596.3
Heating surface, each boiler, square feet:	
Generating tubes	6,162
Area through smoke pipe, total, square feet	139.77
Kind of forced draft	Closed firerooms.
Atomizers, number each boiler	15
type	Schutte-Koerting mechanical atomizers.
Diameter of main steam stop valve, inches	7
main feed stop and check valves, inches	3 1/2
auxiliary feed stop and check valve, inches	3 1/2
surface-blow valves, inches	01 1/2
bottom-blow valves (two), inches	01 1/2
safety valve (two), duplex, inches	04 1/2

FUEL OIL SYSTEM.

The fuel-oil tanks are filled through eight 6-inch connections, two on each side of the ship forward and two on each side of the ship aft.

The two starboard forward filling connections are combined into an 8-inch pipe, which is led to a relay tank located on the third deck, starboard side. The port forward filling pipes are similarly connected to the same relay tank. There is another relay tank aft, located on the third deck, port side; the after filling connections are similarly led to this relay tank.

From each relay tank two 8-inch pipes are led to the distributing manifolds in the center engine room and forward firerooms.

In addition to the main filling connection described above, there are four emergency filling connections, two starboard and two port, each connecting to one of the four distributing manifolds in fire rooms Nos. 1 and 3.

From the bottom of each fuel oil tank 4½-inch pipes, as required, are led to the various distributing manifolds, which are inter-connected so that any pump may be used on any tank. Each tank is fitted with a high suction and a low suction.

Two 6-inch by 8-inch by 12-inch Warren, vertical, piston, double-acting, single, light-service booster pumps are installed in each fire room Nos. 1 and 3. Each pump has a 4½-inch suction connection from the adjacent distributing manifold, and a 4-inch discharge to the distributing manifold, adjacent emergency deck-filling connection, fuel-oil main and overboard; the latter connection is portable. The booster pumps are also arranged to pump settled water from the bottoms of the storage tanks and discharge it overboard through the portable connection referred to above. In addition to the connections noted above, the booster pumps also have a discharge to the deck for fueling the launches and motor boats; also a branch to the galleys and foundry.

There are two heavy-pressure, 5¾-inch by 4-inch by 8-inch, vertical, double-acting, duplex, service pumps of the Warren type in each fire room. Foster, type H-3, pressure governors are provided to control the speed of the units. The pumps have 3-inch suctions from the fuel-oil main and service tanks, and each discharge, through an oil meter and pair of oil heaters, to the atomizer supply pipes. The discharge connections are 2½ inches diameter.

The oil meters are of the Bowser type, and are arranged so that they can be by-passed.

The oil heaters are of the Schutte-Koerting film type, each of 11.52 square feet of heating surface. The oil heaters are arranged so that they can be by-passed.

The atomizers, fifteen per boiler, are carried in two rows on the boiler fronts, with stop cocks at each burner for individual control. They are of the Schutte-Koerting mechanically atomized type. The atomizer-supply pipe to each boiler is fitted with a cutout valve.

Steam coils are fitted near the ends of all suction pipes in all tanks; steam connections for boiling-out the tanks are also provided.

For raising steam with no air pressure available, a 1¼-inch by 3½-inch Schutte-Koerting, vertical, triplex hand pump is

fitted in each fire room, capable of supplying oil at 200 pounds' pressure to two atomizers.

PNEUMERCATOR SYSTEM.

For ascertaining at any time the amount of fuel oil in the various double-bottom tanks, the Parks pneumercator system is installed.

The installation consists of a small semi-spherical balance chamber placed at a predetermined location near the bottom of each tank. The interior of the balance chamber is in communication with the tank, through a hole in the side of the chamber, and a small pipe connects the top of the chamber with its recording instrument at the fuel-oil manifolds. The recording device consists of a glass mercurial tube provided with scale, calibrated to suit the tank to which it is connected.

The instrument operates on the following principle: The pressure due to the head of oil in the tank compresses the air in the chamber and connecting pipe line, which in turn causes the mercury to rise or fall in the tube in direct ratio to the pressure exerted. The tank contents is read off on the scale, as in the case of an ordinary thermometer.

In order to guard against overflowing the tanks when taking aboard fuel oil, an annunciator is installed in connection with the recording device for indicating and signalling when any tank is 95 per cent full.

FORCED DRAFT BLOWERS.

Forced-Draft Blowers.—Each fire room has three forced-draft blowers. They are located in specially constructed blower rooms just below the third deck and above the working flat in front of the boilers.

The fans are No. 20 Keith, horizontal, double-inlet type, each designed to deliver 26,800 cubic feet of air per minute against a static pressure of 4 inches of water, when running at 1,600 revolutions per minute, but capable of delivering, at

slightly reduced output, against a static pressure of 8 inches of water.

Each fan is direct-connected, by a flexible coupling, to a horizontal Terry steam turbine, Type G.

Air is supplied the blowers from a large air duct on the second deck.

The blowers discharge the air into the fire rooms through short trunks, extending through openings in the blower-room floor.

Deflectors are fitted at the trunk outlets, so arranged that the air will be properly diffused throughout the fire rooms.

An automatic hinged shutter, closing by back pressure, is fitted in each blower discharge to prevent the loss of air pressure in the fire room in case a blower stops.

MAIN STEAM PIPING.

The main steam piping is arranged in two symmetrical lines, one on each side of the vessel. There is an 8½-inch cross-connection in the forward and after fire rooms, and one of 4 inches in diameter in the middle fire room. The branches from the wing boilers are 7 inches in diameter each, and those from the center boilers are each divided into two 5-inch branches, one connecting to the starboard and the other to the port steam line.

The main lines are 8½ inches in the forward and middle fire rooms, increasing to 12 and 14½ inches at each successive boiler connection, the latter size continuing to the turbine throttle valves.

In each outboard engine room there are two 10½-inch pipes from each throttle valve to their respective H.P. ahead turbines. There is also a 12-inch connection to each H.P. astern turbine.

A 10-inch pipe cross-connects the main steam lines in the center engine room. It is fitted with a stop valve at each end. From this cross-connection branches are taken as follows: A

10-inch maneuvering connection to each L.P. ahead turbine, a 9-inch maneuvering connection to each L.P. astern turbine and a 10-inch connection to each cruising turbine. All the above connections are fitted with maneuvering valves. All throttle and maneuvering valves are controlled at the working platform in the center engine room.

The piping is seamless drawn steel.

AUXILIARY STEAM PIPING.

The auxiliary steam pipe is seamless-drawn steel.

From the main steam pipe in the after fire room there are two 7-inch connections, reducing to 6½ inches and leading aft through the after dynamo room and forming a loop in the center engine room. The engine room auxiliaries take their steam from this loop.

In the fire rooms the auxiliary steam piping consists of branches from the main steam piping with sub-branches to the various auxiliaries.

The ship's turbo-generator sets take their steam off the main steam cross-connection in the fire room No. 1 and the auxiliary steam lines in the after dynamo room.

Stop valves are fitted in all branches and sub-branches.

AUXILIARY EXHAUST PIPING.

The auxiliary exhaust pipe is led throughout the machinery spaces in continuous loop 10 inches in diameter, with branches leading elsewhere as required for the various auxiliaries. It is cross-connected in the center engine room and all fire rooms. Connections are provided to direct the exhaust steam into either main condenser, either dynamo condenser, either feed-water heater, evaporators, or into the atmosphere through the escape pipe at will.

Stop valves are fitted in all branches, at the main, and in all cross-connections.

ESCAPE PIPES AND ATMOSPHERIC EXHAUST.

There are two 14-inch escape pipes abaft the smoke pipe. Branches from these pipes are led through the third deck to each fire room, where they are further subdivided and connected to the individual safety valves through 6-inch branches.

There are two 8½-inch branches, starboard and port, in fire room No. 3 from the auxiliary exhaust to the escape pipe for atmospheric exhaust. A stop valve is fitted at each connection to the escape pipe.

There is also a 10-inch atmospheric exhaust connection, fitted with automatic valve, from each dynamo turbine to the escape pipes.

All the above piping is copper.

MAIN AND AUXILIARY FEED SYSTEMS.

Feed and Filter Tanks.—Two feed and filter tanks of 5,200 gallons' capacity each, are located in each center engine room. A filter chamber of about 900 gallons capacity is in the top of each tank. Each filter chamber has an inner bottom of loose perforated plates and is divided into three compartments, in which is placed the filtering material, by vertical division plates. These partitions are so arranged that the water in passing through the filter will flow under and over in succession, thus assuring the filtering material being always submerged.

Each tank is provided with the following principal connections:

1 10½-inch main air pump discharge;
1 4-inch reserve-feed pump discharge;
1 12-inch cross-connecting pipe;
1 8-inch overflow;
steam drain discharges;
vapor pipes.

Feed-Water Heaters.—There is a Reilly multicoil feed-water heater in each fire room.

Each heater has 239.85 square feet of heating surface, and a rated capacity of 166,700 pounds of water per hour from 100 degrees F. to 200 degrees F., with steam at 10 pounds gage.

The heating agent is the exhaust steam, a back pressure of about 10 pounds gage being kept in the auxiliary exhaust line for this purpose by means of a spring-relief valve at each connection to a condenser, opening toward the condensers.

Main Feed Pumps.—There are three horizontal, direct-connected, turbine-driven, centrifugal main feed pumps located in the center engine room. The speed of the pumps is controlled by "Ideal" pressure governors. Centrifugal, emergency-trip, over-speed, governors are also provided.

The following is the principal pump and turbine data:

Pump—Make and type, Worthington, 5-inch, horizontal, 4-stage, volute, Class M. S.
Capacity, each, 500 G.P.M.
Head, 850 feet.

Turbine—Make and type, Terry, Type G, horizontal, single stage.
Horsepower, each, 180.
R.p.m., 3,000.

Auxiliary Feed Pumps.—An auxiliary feed pump is installed in each of the three fire rooms. They are of the Warren, 16-inch by 10½-inch by 24-inch, vertical, piston, double-acting, single type. "Foster," Type H, governors are provided for the speed control of these pumps.

Reserve Feed Pumps.—A Warren, 6-inch by 8-inch by 12-inch, vertical, piston, double-acting, single, reserve feed pump is installed in the fire room No. 2. It is arranged to pump water from the reserve-feed tanks to the main feed tanks. It also has a suction connection from the hotwell-pumps cross-connection. An 8-inch by 8-inch by 12-inch, vertical, piston, double-acting, single pump, of the Boston Navy Yard type, is installed in the center engine room for similar service.

Piping Arrangement.—The feed piping is seamless-drawn copper.

Each main feed pump has a 6-inch suction from the 12-inch feed suction main, which connects to the main feed tanks through the cross-connection.

The discharge from each main feed pump is 5 inches, uniting in the center engine room into an 8½-inch line, which leads forward and diminishes in size as it advances to 5 inches in the forward fire room. There is a 5-inch connection in each fire room to the respective feed water heaters. The feed water heaters are fitted with bypasses. The supply branches to each boiler are 3½ inches.

The feed suction main reduces in size as it leads forward to 11 inches, 9 inches and 6 inches. All auxiliary feed pumps have a 6-inch suction connection from the main.

Each auxiliary feed pump is arranged to discharge to the boilers in its compartment, through the feed-water heater or direct. They can also discharge into the main feed-discharge line to the boilers in other compartments. The discharge connection from each pump is 5 inches in diameter, and the supply branches to the boilers are 3½ inches diameter each.

INTERIOR COMMUNICATION.

The customary engine and fire room telegraphs, gongs, telephones, voice tubes, etc., are fitted for transmitting orders and signaling to the various machinery compartments and other parts of the vessel.

AIR COMPRESSOR PLANT.

An air compressing plant is provided for ejecting gas from the guns, cleaning boiler tubes, cleaning dynamos, running pneumatic tools, etc.

The plant is divided into two parts, each consisting of two motor-driven, geared, compressors and two air-storage tanks, together with switchboards and appurtenances. One group of

equipment is located forward on the third deck in the windlass room, and the other is located on the third deck aft of No. 3 barbette and enclosed in a wire-mesh bulkhead.

The air compressors are automatically controlled so as to maintain a constant pressure on the system. They are also provided with automatic unloading valves so that after shutting down the compressor will always be started up in the unloaded condition.

There is a pneumatic main running through the machinery space with nozzles in each compartment. Branches from this main are led to the general workshop, dynamo, ice-machine and evaporator rooms, galleys, etc., as required. The main is connected to all the air compressors.

The main for ejecting gas from the guns is independent of the above mentioned pneumatic main, and is likewise connected to all the air compressors.

The following are the principal characteristics of the air compressors:

Make—Worthington, motor-driven, geared.
Size—15-inch by 12¾-inch by 7-inch stroke.
Capacity, each—175 cubic feet of free air per minute at 150 pounds' pressure per square inch.
R.p.m., compressor, 300.
R.p.m., motor, 1,600.
Horsepower of motor, 45.
Capacity air-storage tanks, each, cubic feet, 40.

EVAPORATING AND DISTILLING APPARATUS.

The evaporator room is on the second platform between the engine and fire rooms, starboard side. The plant is arranged to operate in double-effect with live steam at 70 pounds gage in the first-effect steam coils, or in single-effect when using auxiliary exhaust steam at about 10 pounds gage. Under the latter condition a slight vacuum is maintained on the distillers, an air pump being provided for the purpose.

The plant has a combined nominal capacity of 80,000 gallons of water per 24 hours, when operating in double effect, with a 40 per cent overload capacity when clean.

EVAPORATOR DATA.

Type	Griscom-Russell, multicoil.
Number	4
Diameter, inside, inches	56
Height over all, feet and inches	7–6
Coils, number (each)	40
diameter of pipe, inch	1
thickness of pipe, inch	0.065
Heating surface, square feet (each)	120
Diameter of steam connections (2), inches	3
drain connections (2), inches	1¼
vapor nozzle, inches	4½
feed valve, inches	1½
blow valves, inches	3

DISTILLER DATA.

Type	Griscom-Russell, multicoil.
Number	4
Diameter, inside, inches	34
Length, over all, feet and inches	4–6¼
Coils, number (each)	20
diameter, inch	1
thickness, inch	0.065
Cooling surface, square feet (each)	136
Diameter of circulating water inlet and outlet, inches	4½
vapor inlet, inches	4½
drain, inches	2

EVAPORATOR VAPOR FEED WATER HEATER DATA.

Type	Griscom-Russell, Bureau U-tube.
Number	2
Tubes, number (each)	28
diameter, inside, inch	0¾
thickness, inch	0.065
Heating surface, square feet (each)	23
Diameter of feed inlet and outlet, inches	2
vapor inlet and outlet, inches	4½

PUMP DATA.

Evaporator feed pumps:
Number and type—(2)—Warren, vertical, piston, double-acting, single.
Size....4½-inch by 5-inch by 6-inch.
Evaporator brine pump:
Type....Warren, vertical, piston, double-acting, single.
Size....4½-inch by 5-inch by 6-inch.
Distiller circulating pumps:
Number and type—(2)—Worthington, horizontal, turbine-driven, 6½-inch, Class B, Volute.
Capacity (each), G.p.m. at 25 feet head.... 800
Turbine, type Z.... Terry.
R.p.m.... 2,000
Horsepower (each).... 12
Distiller fresh-water pumps:
Number and type—(2)—Warren, vertical, piston, double-acting, single.
Size....4½-inch by 5-inch by 6-inch.
Distiller air pump:
Type—Warren, vertical, piston, double-acting, single, featherweight.
Size....6-inch by 10-inch by 8-inch.

A Cochrane precision meter is provided for measuring the fresh water produced by the plant.

GENERAL WORKSHOP.

The following machine tools, each driven by its own electric motor, are installed in the machine shop on the third deck, over the center engine room:

No.	Description.	Make and H.P. of motor.
1	28-inch by 48-inch swing, extension-gap lathe; "Harrington"	G. E. Co., 5 H.P.
1	14-inch swing lathe; "Prentice"	G. E. Co., 2 H.P.
1	14½-inch swing lathe; "Prentice"	G. E. Co., 2 H.P.
1	8-inch swing precision lathe; "Hjorth"	1½ H.P.
1	24-inch column shaper; "Cincinnati"	G. E. Co., 5 H.P.
1	30-inch radial drill; "Dreses"	G. E. Co., 2 H.P.
1	16-inch sensitive drill, "Willey"	½ H.P.
1	Universal milling machine; No. 2 "Rockford"	G. E. Co., 2 H.P.
1	Floor grinder; Willey	1 H.P.

1 Portable cylinder-boring machine; "Underwood" ..... G. E. Co., 2 H.P.
1 Portable cylinder-boring machine; "Underwood," pneumatic-drive.
1 Portable surface grinder; "Willey" ..... 1 H.P.
1 4-inch hacksaw; "Willey."
1 Portable drill; No. 3 "Willey."

BLACKSMITH SHOP.

A blacksmith shop is provided on the superstructure deck, in the foundry enclosure. It is equipped with one portable and one permanent forge, together with anvil and all necessary tools and fittings. The permanent forge is oil burning; it is fitted with an electrically-driven blast fan. The portable forge is of the coal-burning folding type.

FOUNDRY.

A small foundry is installed on the superstructure deck. The outfit consists of a small marine, oil-burning, crucible furnace, together with adequate allowance of crucibles and the necessary apparatus for handling and pouring the metal.

PIPE AND COPPERSMITH SHOP.

The pipe and coppersmiths' equipment is located on the third deck in the general workshop, and consists of the following:

1 Motor-driven, pipe-cutting and threading machine; ½-inch to 3-inch capacity; No. 34 "Curtis and Curtis";
1 tinner's combined punch and shears; No. 3 "Peck, Stow & Wilcox";
1 tinner's slip roll forming machine; 6-inch by 36-inch "Niagara";
1 tinner's beading machine; "Peck, Stow & Wilcox";
1 tinner's cornice brake; "Peck, Stow & Wilcox";
1 oxyacetylene welding outfit; "Milburn";
1 oil forge;
vises, work-benches, etc.

ELECTRIC PLANT.

There are two dynamo rooms, one just forward of the forward boiler room and the other just aft of the after boiler room. They are on the second platform level.

The distribution rooms, two in number, are located on the first platform, one over each dynamo room. They contain the lighting, power, searchlight and generator boards combined.

The generator installation consists of four horizontal, 6-pole, compound-wound, 300-kilowatt, 3-wire, General Electric generators, two in each dynamo room; they are gear-driven by three-stage horizontal Curtis turbines, designed to run at 5,037 revolutions per minute, with steam at 200 pounds gage. Each generator will deliver at normal load 1,250 ampères of current at 240 volts, when running at 1,000 revolutions per minute. The generators are capable of delivering one-third overload for two hours without injury.

Steam for the generators is taken off the main steam cross-connection in the forward fire room, and auxiliary steam line aft, for the forward and after generators, respectively. The branch to each generator is 4 inches and fitted with stop, reducing and throttle valves.

The generators are arranged with condensing and atmospheric exhaust, the latter connections, via escape pipe, are 10 inches and fitted with automatic valves permitting instantaneous change over in emergency.

Each pair of generators has an independent condensing apparatus, located below the generators in a separate room in the hold, with access hatch between the two levels. Each condensing apparatus consists of one condenser, two air ejectors, condensate pump, circulating pump, hotwell-tank pump and hotwell tank of 316 gallons' capacity. No air pumps are provided.

With this system of vacuum producing apparatus, air and non-condensable vapors are drawn off the condenser by steam air ejectors, which discharge into the hotwell tank where the

air is liberated and escapes to the atmosphere through the vapor pipes on the tank. The condensate is removed from the bottom of the condenser by a special turbo-centrifugal pump, which discharges same into the hotwell tank. A 1-inch diameter circulating pipe is fitted between the hotwell tank and the condenser for use when starting the apparatus, otherwise, owing to the absence or insufficiency of condensate, the water in the tank would quickly become overheated, due to the ejector steam discharging therein.

The dynamo condensers also handle the auxiliary exhaust in port.

DYNAMO CONDENSER DATA.

Number	2
Inside diameter, feet and inches	4–0
Thickness of shell (steel), inch	0¼
Length between tube sheets, feet and inches	7–1
Thickness of tube sheets, inch	1
Tubes, number (each)	1,385
diameter, outside, inch	0 ⅝
thickness, inch	0.065
Cooling surface, square feet (each)	1,000
Diameter of exhaust nozzles, generators (2), inches	18
air ejector suction, inches	3½
condensate pump suction, inches	4
circulating-water inlet and outlet, inches	9
auxiliary exhaust nozzle, inches	10

AIR EJECTOR DATA.

Make	Westinghouse-LeBlanc.
Type	2-stage, Size B.
Number per condenser	2
Number of steam nozzles, first stage	3
second stage	6
Diameter, steam inlet, inch	0¼
air inlet, inches	2½
discharge, inches	2

PUMP DATA.

Dynamo condenser circulating pumps:

Number and type—(2)—Worthington, horizontal, turbine-driven, 9-inch, special, class B, Volute.

Table I - U.S.S. IDAHO - Four Hours

Date of trial				
Draught, mean on trial, feet and inches				
Displacement, corresponding, tons				
Speed in knots				
Slip of propellers, per cent., outboard				
inboard				
mean				
Number of boilers in operation				
Total heating surface, square feet				
Pressures (Average):		**Starb'd**		**Port**
Main steam, at boilers, lbs. gauge			241	
engine room, lbs. gauge		227		228
H.P.ahead turbine, chest, lbs. gauge		153		145
2nd expansion, lbs.gauge		--		65
astern turbine, chest, lbs. gauge		0		10
L.P.ahead turbine, chest, lbs. gauge		15		15
astern turbine, " , " "		3		7.5
Cruising turbine, chest, lbs. gauge		0		7
Vacuum, main cond., inches of mercury		28		28.7
Barometer, inches of mercury			30.1	
Auxiliary steam, lbs. gauge		224		223
exhaust, lbs. gauge		9.9		9.5
Gland steam, lbs. gauge		11		5
Steam to fuel oil heaters, lbs. gauge			224	
Main feed, at pumps, lbs. gauge			241	
Forced lubrication, lbs. gauge		20		15
Fuel oil service pumps, lbs. gauge			204	
Air pressure in firerooms, inches of water			4.8	
Revolutions or Double Strokes per Min.(Average):				
No. 1 shaft			234.81	
No. 2 "			242.29	
No. 3 "			241.58	
No. 4 "			255.18	
Mean all shafts			238.48	
Main air pumps	(2)	18		19
" feed pumps	(3)		2785	
" circulating pumps	(2)	1059		1014
Oil cooler circulating pumps	(2)	27		42
Lubricating oil pumps	(2)	24		43
Fuel oil service pumps	(3)		30	
" " booster "	(1)		30	
Forced draft blowers	(8)		1585	
Fire and bilge pump	(1)		43	

* On basis of 19,500 B.T.U. per pound.
Figures in parentheses indicate number of units in operation.

our Hours Full Power Trial.

- - - - - -	Sept.29, 1919.
l inches - -	30 - 8-1/16
ns - - - - -	32,819
- - - - - -	21.29

	Starb'd	Port
outboard - -	15.25	15.66
inboard- - -	15.91	15.66
mean - - - -	14.56	
- - - - - -	9	
eet- - - - -	56,458	

	Starb'd	Port
Shaft Horse Power (Average):		
No. 1 shaft - - - - - - - - - -	Torsion meter out of order	
No. 2 " - - - - - - - - - - - - - -	7764	
No. 3 " - - - - - - - - - - - - - -	9266	
No. 4 " - - - - - - - - - - - - - -	7871	
Total from standardization curve- - -	33100	
Temperatures, Degrees F. (Average): - -		
Main feed tanks - - - - - - - - - - -	112	119
" air pump discharge - - - - - - -	82	86
" injection - - - - - - - - - - -	57	57
" overboard discharge- - - - - - -	78	81
Outside air - - - - - - - - - - - - -	62	
Engine room, floor level, outboard- -	83	89
center- - -	88	
Fire rooms, floor level - - - - - - -	96	
Feed, to heater - - - - - - - - - - -	105	
from heater - - - - - - - - - -	164	
Fuel oil, to heaters- - - - - - - - -	73	
from heaters- - - - - - - -	137	
Lubricating oil, to cooler- - - - - -	102	97
from cooler- - - - -	91	82
Water from oil cooler - - - - - - - -	80	87
Smoke pipe- - - - - - - - - - - - - -	755	
Fuel Oil Data:		
Kind- - - - - - - - - - - - - - - - - -	California	

Capacity (each), G.p.m. at 20 feet head..... 2,200
Turbine, type Z .....Terry.
R.p.m. 1,275
Horsepower (each) 14.4

Dynamo condensate pumps:

Number and type—(2)—Westinghouse, impeller pump, turbine-driven, size 02.

Dynamo condenser hotwell pumps:

Number and type—(2)—Warren, vertical, piston, double-acting, single.
Size.....4½-inch by 5-inch by 6-inch.

TRIALS.

The contract required an extensive series of trials, but this requirement was considerably modified due to the pressure of war, and the *Idaho* was commissioned following a very complete and successful dock trial, which was conducted at the builder's yard, February 17 and 18, 1919.

The final trials of the vessel, consisting of a four hours' full speed trial and a standardization trial, were run September 29, and October 1 and 2, 1919, respectively. All trials were conducted off the Pacific coast. The measured mile off Santa Barbara, California, was used for the standardization trial.

The results of the four hours' full speed trial are given in Table I.

NOTES.

WIRELESS TELEPHONY.*

By N. H. Slaughter, D.S.M.

ENGINEERING DEPARTMENT, WESTERN ELECTRIC COMPANY, NEW YORK, N. Y.
(FORMERLY) LIEUT. COL., SIGNAL CORPS, U. S. A.

FUNDAMENTAL REQUIREMENTS.

The development of wireless telephony dates back almost as far as the original conception of the use of electromagnetic waves for wireless telegraphy. The practical utilization of this method of communication is, however, a matter of comparatively recent date as contrasted with the much longer period during which wireless telegraphy has been a practical accomplishment. This delay in the successful utilization of wireless telephony is due to certain differences in the fundamental requirements as compared with those for the telegraph. These differences and the manner in which the particular difficulties incident to the successful accomplishment of wireless telephony have been overcome will be explained in detail in succeeding paragraphs.

Broadly speaking, the principal difference between wireless telephony and wireless telegraphy lies in the form of the signal which has to be transmitted, telegraph signals being obviously far simpler in the wave-form of the signal current than are telephone signals. The fundamental requirement is, in either case, that the form of the receiving signal shall faithfully reproduce the form of the transmitted signal, whether due to the opening and closing of a telegraph key or the vibrations of a telephone transmitter diaphragm.

The essential units required in a complete wireless telephone system may be grouped into the transmitting and the receiving elements. The receiving elements, being in no respect different from those required in wireless telegraphy, will not be described at this point. The transmitting elements differ, however, in many respects and comprise the following essential units:

A radio frequency generator.

A modulator for controlling the radio frequency current.

An antenna for radiating the electromagnetic waves produced by the radio frequency current.

The particular characteristics of these various units are described in detail hereinafter.

Wireless telephony is subject to certain particular limitations in the same way as wireless telegraphy, notably that of interference due to atmospheric electricity or radio signals foreign to the desired signal.

HISTORICAL SUMMARY.

The first requirement for any wireless telephone station is a source of radio frequency current whose amplitude from cycle to cycle remains constant, except when varied by the modulation imposed upon it by the voice current. If variations in its amplitude occur, due to other causes, these variations will introduce disturbances which will cause the system

* Presented at a joint meeting of the Electrical Section and the Philadelphia Section, American Institute of Electrical Engineers, held Thursday, October 30, 1919.

to be deficient in the effective transmission of speech. It is at once evident that the original source of radio frequency current used in wireless telegraphy, namely, the oscillatory discharge of a condenser supplied with energy from a low frequency source, is entirely unsuited to the purposes of wireless telephony.

With the development of the Poulsen arc the first successful attempts at radio telephony were begun. These attempts involved the second factor in a wireless telephone station, namely, that of modulating the radio frequency current in accordance with the currents supplied by a telephone transmitter. The early attempts to accomplish this modulation, by means of microphones inserted directly in the antenna circuit or coupled to the circuit in various manners, were largely unsuccessful due to the limitations of the microphone devices, such as the low current capacity and the small range of variation of resistance.

A second source of radio frequency current is the high frequency alternator, which has been developed in various forms and which has been likewise used with limited success for wireless telephone transmission. The same lack of a suitable modulating device handicapped the use of the high frequency alternator until the advent of the audion or vacuum tube. The characteristics of the vacuum tube have been fully described in many recent publications, and will be discussed in this paper only in so far as these characteristics are directly applicable to the problems of wireless telephony. It will be seen from this subsequent discussion that the vacuum tube possesses in a remarkable manner the precise characteristics required for the generation and modulation of radio frequency current for low power wireless telephone stations, and for the detection and amplification of radio signals of any character whatsoever. Its influence on the art of wireless telephony may well be compared with the influence of the gas engine on aviation.

VACUUM TUBE.

The requirements of a radio frequency generator may be grouped as follows:

The desired frequency may range roughly between the values of 15,000 and 6,000,000 cycles per second.

The frequency for any particular generator may be required to vary over a considerable range, in some cases as much as several octaves. In other cases, a single value of frequency is sufficient.

The frequency when set at a particular value should remain substantially unaffected by ordinary changes in the physical or electrical conditions associated with the station.

The current delivered by the generator should approximate a sine wave as closely as possible.

The required output for different classes of stations may vary from less than one watt to several hundred kilowatts.

The efficiency of the generator should be reasonably high though not necessarily comparable with the efficiencies obtained from ordinary types of generators.

When used as an oscillator or radio frequency generator associated with properly designed circuits, the vacuum tube will meet all of these requirements, with the exception that the power output of vacuum tubes as at present constructed is limited to not more than a few hundred watts per tube.

The requirements of a modulator for radio telephony may be grouped as follows:

The modulator should be actuated by the current from an ordinary microphone telephone transmitter or its equivalent.

The modulator should faithfully reproduce, in its effect upon the radio frequency current, the wave-form of the telephone or speech current.

The modulator should be capable of almost completely modulating the output of radio frequency generators whose power outputs may cover the range indicated above.

These requirements are fulfilled to a remarkable extent by the vacuum tube used in properly designed circuits.

Although the vacuum tube was invented in 1906, its development into a sufficiently practical form to be useful for wireless telephony was comparatively slow. This development was greatly accelerated, beginning in 1912, when the American Telephone and Telegraph Company became interested in the vacuum tube for use in telephone repeaters. Rapid improvements were made in the design and construction of vacuum tubes, and at the same time experiments were conducted looking to the use of the vacuum tube in wireless telephone apparatus. As a result of these experiments, the transmission of speech from Washington, D. C., to Paris and to Honolulu by wireless telephone occurred during the year 1915. In these experiments the vacuum tube was used as a radio frequency generator, a modulator, a detector and amplifier.

The possibilities of the vacuum tube for wireless telephony having been partly disclosed by the above experiments, the Navy Department became actively interested in the development of wireless telephone apparatus for use on battleships. Experimental sets were developed by the Western Electric Company and extremely promising results were secured. The Signal Corps was likewise interested in the development of apparatus for the Army, but experiments had not proceeded to the point where any satisfactory apparatus had been developed prior to the declaration of war by this country.

FIELD OF MILITARY APPLICATION.

Prior to the beginning of the European War the use of wireless telegraphy in military operations had been limited to an extremely narrow field, while wireless telephony had been used to an entirely negligible extent. The communication requirements for the armies engaged in the trench-warfare style of conflict emphasized the need of radio communication, and accordingly the extent and variety of the apparatus for wireless telegraphy increased rapidly. At the time this country entered the war wireless telegraphy comprised an extremely important and extensive part of the communication systems employed on the western front. The development of wireless telephony, however, had not proceeded to the point where satisfactory apparatus was available for use by the military forces. The particular field which most urgently required its use was the airplane communication system. The limitations imposed on the use of wireless telephony, such as greater weight and complication of the apparatus, and complete lack of secrecy, had hitherto prevented favorable consideration of wireless telephony as a substitute for wireless telegraphy. The particular requirements of the airplane communication, however, introduced certain advantages which more than compensated for these factors and made telephony much more desirable than telegraphy. The controlling reason for the use of the wireless telephone lay in the fact that its use eliminated the necessity of a knowledge of the telegraph code on the part of the aviator. An additional advantage lay in the greater speed with which the telephone transmission can be effected.

Inasmuch as the airplane wireless telephone set comprises not only the most interesting example of the use of wireless communication during the war, but furnishes also a remarkable example of the rapidity with which the engineering and manufacturing facilities of this country were adapted to war-time needs, a detailed summary of the development, production and operation of this set forms an important part of the general subject of wireless telephony.

HISTORICAL REVIEW.

Almost immediately following the declaration of war by this country, the Chief Signal Officer of the Army issued orders for the development of an airplane wireless telephone set which was to furnish telephone communication between the different airplanes of a squadron and also to furnish communication between an airplane and a ground station. The fundamental requirements for this set were based partly on information furnished by the Allies, and partly on the experience of the U. S. Signal Corps in the pre-war experiments in airplane radio telegraphy and telephony. The actual development work was entrusted to the Engineering Department of the Western Electric Company, with provision for the necessary airplane facilities and information to be supplied by the Signal Corps as required. The progress of the development work was extremely rapid, successful communication being established between an airplane and a ground station within six weeks from the date the development was started. The evolution of a complete design suited to commercial production likewise proceeded very rapidly, so that by December, 1917, only six months from the time the development work was started, the design of the complete equipment had reached the stage where production of the sets in quantity could be authorized. As early as October, 1917, the apparatus had been developed to a sufficiently complete extent to warrant sending samples to the Expeditionary Forces for test under conditions existing at the front.

Because of the extreme need for the earliest possible delivery of apparatus in large quantities, to meet the needs of the airplane program of the United States, the production of airplane telephone sets was begun prior to the completion of the experimental work. As further experiments indicated the need of modification or refinements in the design, the necessary changes were incorporated in the process of manufacture, so that the sets delivered in the spring of 1918 embodied the results of experimental work extending almost up to the date of completion of the sets.

Beginning early in the summer of 1918 the development of an improved type of set was begun, and at the time of the armistice this development had reached the point where practical trials of the completed sets were in progress. The essential differences between the original type of set and this new set are described in some detail in succeeding paragraphs.

The production of several thousand of the airplane wireless telephone sets in the brief space of a few months involved many problems of an extremely unusual and difficult nature. As an example may be cited the production of the vacuum tubes required for use in the sets. Prior to the war the vacuum tubes had never been produced at rates greater than a few hundred tubes per week. At the time of the armistice the production of these tubes in one factory alone was in excess of 25,000 per week, the largest part of which was intended for use with the airplane wireless telephone sets. The problem of devising methods for testing the completed sets involved the development of unusual testing facilities and the creation of a large organization of inspectors to handle the sets as

rapidly as they were delivered from the factory. It was obviously impossible to test each completed set in an airplane before considering it as finally accepted, so that the formulation of the testing specifications involved the development of tests which would approximate the conditions encountered on airplanes and at the same time would be adapted to factory methods of testing.

Before the development of the airplane wireless telephone sets had proceeded even to the point where success was assured, it became apparent to those involved in the work that the production of a satisfactory set was by no means the complete solution of the problem. The successful use of the equipment would undoubtedly require a considerable amount of training of the aviators and a very considerable period of experiment with the trained aviators using the equipment before its limitations and its possibilities could be even approximately determined. Accordingly preparations were made in advance of the delivery of the first production sets, to institute a course of training which was intended both to familiarize the aviator with the actual use of the set and to work out the method of use; in other words, the tactics of a voice-commanded airplane squadron. As early as May, 1918, groups of airplanes using the wireless telephone sets were being trained in the use of this equipment and were being drilled in the evolutions which the equipment made possible. In June, 1918, a squadron of 39 airplanes, equipped with wireless telephone sets, went through a course of drill in the air in such a manner as to demonstrate the remarkable possibilities of a voice-commanded squadron. Subsequently the training of aviators in the tactics of "V. C." flying progressed at a rapidly increasing rate, so that at the time of the signing of the armistice many thousand flights had been made. The record of these flights is a glowing tribute to the efficiency of the design of the airplane wireless telephone sets, which performed in such a manner as to give far less trouble than the airplane engine.

AIRPLANE SETS.

At the outset of the war-time development work on the airplane wireless telephone apparatus the requirements which the apparatus would have to meet and the particular conditions under which it would operate were largely unknown; this information became apparent more or less gradually during the progress of the development work, which fortunately proceeded along such lines as to substantially comply with the requirements as they developed. As originally conceived, these requirements may be briefly stated as follows:

The apparatus should be capable of effecting reliable telephone communication between two airplanes at distances up to 2,000 yards.

The weight of the apparatus should be the minimum possible consistent with meeting the range requirements and other conditions imposed on the operation.

The apparatus should be of the simplest possible construction and should require the minimum amount of adjustment or manipulation by the aviator.

It was realized that special conditions would be encountered on the airplane which would make the development work extremely difficult and would require radical departures from any previous practice. Among these special conditions may be mentioned the tremendous noise and vibration created by the engine and wind, the necessity of reducing the fire hazard to a minimum, and, above all, the extremely essential condition that the wireless telephone apparatus must create the minimum possible interference with the various other functions of the aviator.

The various elements comprising the complete wireless telephone set may be grouped into the following units:

Power Plant.
Transmitting Unit.
Receiving Unit.
Antenna System.

The details of these various units and the problems encountered in their development are briefly described in the following paragraphs:

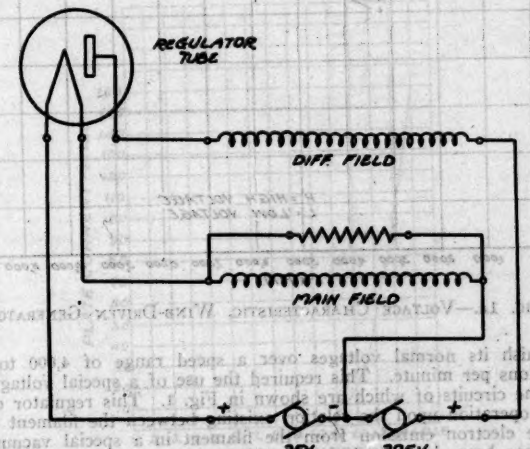


FIG. 1.—CIRCUIT DIAGRAM, WIND-DRIVEN GENERATOR.

POWER PLANT.

The preliminary experiments with various types of apparatus soon determined the power requirements of the apparatus which included power supply for the filament and plate circuits of the vacuum tubes for both transmitting and receiving circuits and power for the telephone transmitters. The filament power required was determined to be 1.35 amperes at 24 volts and the plate circuit power for the transmitting set .070 amperes at 275 volts. The plate current for the receiving tubes was extremely small, namely, less than .004 amperes, and it was decided to furnish this power from dry batteries. After various arrangements were tried the current for the telephone transmitter was obtained by shunting this transmitter about filaments of two vacuum tubes which gave approximately the correct voltage for operating this transmitter. The 24-volt and 275-volt power is obtained from a double voltage direct current generator which is driven by an air fan, the complete generator being mounted on one of the struts of the landing gear of the airplane and hence being directly in the propeller blast. The most difficult problems involved in the design of the generator were those related to the excessive speed variation and the extremely high maximum speed at which the

generator was required to operate. The air speed of the plane being subject to extremely wide variations and the air fan rotational speed varying in almost exactly the same ratio, it was necessary for the generator

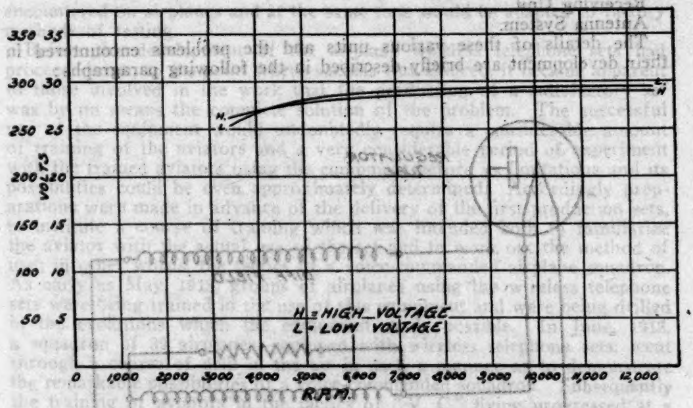


FIG. 1A.—VOLTAGE CHARACTERISTIC, WIND-DRIVEN GENERATOR.

to furnish its normal voltages over a speed range of 4,000 to 12,000 revolutions per minute. This required the use of a special voltage regulator, the circuits of which are shown in Fig. 1. This regulator depends for its operation upon the relation existing between the filament current and the electron emission from the filament in a special vacuum tube which has been designated as a regulator tube. At the lower limit of the operating speed range, namely, 4,000 revolutions per minute, the filament of this regulator tube operates at a temperature which gives practically no emission of electrons. As the speed of the generator increases above this value the voltage rises, and accordingly the temperature of the regulator tube filament increases. This results in an extremely rapid increase in the number of electrons emitted by the regulator tube filament, which in turn causes a rapid increase in the current flowing through the differential field and the plate circuit of the regulator tube, as shown by the characteristic curves of Fig. 2. This current tends to reduce the total magnetization of the generator, and, as a result, the voltage regulation is maintained within extremely close limits.

While this voltage regulating device operates in an extremely satisfactory manner, the excessive speed variation of the generator imposes certain other requirements on the generator design which make it desirable to reduce this speed variation. The development of a constant speed air fan has progressed practically to the point where designs are available for an air fan which will give an almost exactly constant rotational speed with a range of air speeds of at least 4 to 1. The use of such an air fan on future wind-driven generators for airplanes is a practical certainty.

Various alternatives, such as storage batteries and a dynamotor, or a double voltage generator driven directly from the airplane engine, were considered and rejected in favor of the generator above described.

TRANSMITTING SET.

The circuits of the transmitting set are shown schematically in Fig. 3. A single vacuum tube of a special type is used for furnishing the radio frequency current and a similar tube is used for modulating the radio frequency current. The method of modulation employed is known as the "constant current" method and may be described briefly as follows:

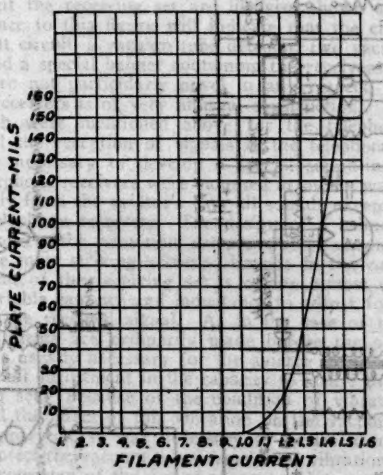


FIG 2.—CHARACTERISTIC CURVE, REGULATOR TUBE.

The plate circuits of the vacuum tube oscillator and modulator are connected in parallel and are supplied through an inductance coil, which tends to maintain the total current constant. The plate current taken by the modulator tube is controlled by its grid voltage, which in turn is determined by the operation of the telephone transmitter. These voice frequency fluctuations of the modulator plate current cause corresponding variations in the direct current supplied to the plate circuit of the oscillator tube, the sum of the two currents at any particular instance being substantially constant. These variations in the direct current supply of the oscillator tube result in corresponding variations of its high frequency output so that the result is a modulated radio frequency current supplied to the antenna.

The telephone transmitter furnished one of the most difficult problems in connection with the design of the transmitting set by reason of the fact that this transmitter operates under conditions of such extreme noise due to the wind and engine exhaust. After a very extended period of development the present form of transmitter was perfected, its improvement over the ordinary form being roughly indicated by the statement that the ratio of noise signals to speech signals in the output of this transmitter is probably less than 1 per cent of the same ratio for a transmitter of the usual type.

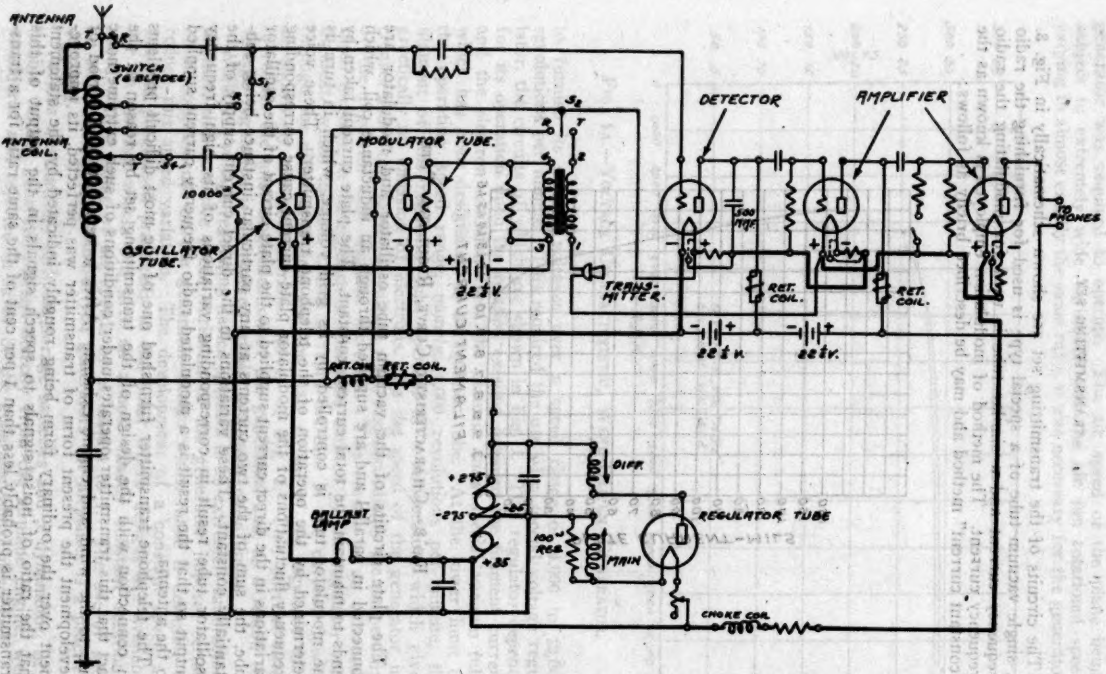


FIG. 3.—SCHEMATIC DIAGRAM, AIRPLANE WIRELESS TELEPHONE.

Reference to the schematic diagram indicates the adjustments of the transmitting set for different wave-lengths to include only a variable inductance and a variable capacity. Inasmuch as the apparatus is adjusted for a particular wave-length before the airplane leaves the ground, an artificial antenna whose constants approximate those of the normal antenna is used for making such adjustments on the ground.

RECEIVING SET.

The circuits of the receiving set are likewise shown schematically in Fig. 3. Reference to this figure will indicate that the circuit comprises a single resonant circuit, a vacuum tube detector, two vacuum tubes used as amplifiers, and a special helmet containing the receivers. The detector and amplifier are not particularly novel in any respect, but the helmet containing the receivers is of very unusual construction. The same noise conditions which were mentioned above for the telephone transmitter likewise affected the reception of signals in the telephone receivers. It was accordingly necessary to develop a special sound-insulating helmet in which the telephone receivers were mounted in such a way as to exclude almost completely from the aviator's ears all sounds except those emanating from the telephone receivers. The design of a helmet which would accomplish this and at the same time not prove to be uncomfortable represents one of the most striking accomplishments in the complete set.

The adjustment of the receiving set is of the utmost simplicity, there being only a variable capacity and inductance to adjust for the particular wave-length of the received signal. As in the case of the transmitting set, these adjustments are ordinarily made before the plane leaves the ground, and it is usually necessary for the aviator to make in flight only an extremely small adjustment in the capacity to insure the proper tuning of the receiving set. Because of the condition of vibration existing on the airplane and the effect of this vibration on the vacuum tubes used in the receiving apparatus, it was necessary to devise a mechanical filter which would protect the vacuum tubes from these vibrations. The method finally adopted consisted of the use of sponge rubber supports for certain elements within the set box itself.

The current required by the plate circuits of the receiving tubes and the negative grid potential for the modulator tube of the transmitting set are furnished by small dry batteries, which consist of 15 cells of very special construction weighing less than one pound and having sufficient current capacity to operate the set a few hours a day for a considerable number of weeks. The most important requirement for these batteries, however, was a sufficient length of shelf-life, inasmuch as a period of several months usually elapsed between the date of manufacture and the date of use. Difficulties of securing even a few months' shelf-life for cells of such small size made the use of standard cells out of the question. Development of particular types of containers for the cells and extremely careful selection of materials resulted in the satisfactory solution of this problem.

ANTENNA.

The form of antenna which was adopted for the early experiments with the airplane wireless telephone consisted of a wire trailing behind the airplane in flight and connected through the apparatus with the frame of the airplane as a counterpoise. The length of this wire was ordinarily 300 feet. A reel was provided for holding this wire and a small weight was attached to the free end to cause it to unreel properly after the air-

plane left the ground. In order to reduce the attention required by the aviator in unreeling the antenna a special form of reel was devised with a centrifugal governor, which limited the unreeling speed to a value which prevented the weight from breaking the wire at the end of the unreeling process. The wire which was used was a soft braided copper wire made purposely of low tensile strength, so that in case this wire became entangled with any obstruction during flight no particular strain would be put upon the airplane structure before the antenna wire would break.

The subject of radiation from airplane antennæ has perhaps received less attention in proportion to its importance than almost any other phase of airplane wireless telephony. This is partly due to the fact that the form of antenna above described possesses extremely efficient radiating properties and partly to the fact that investigations of the subject require very extensive and painstaking measurements involving actual flights of airplanes. The investigations conducted during the war, however, included a large number of tests of various types of antenna, the principal object of which was to evolve a substitute for the long trailing wire which would be better adapted for use on airplanes engaged in acrobatic flying. Obviously the movements of an airplane were somewhat restricted by the use of this type of antenna.

Without indicating in detail any of the alternative types of antenna which were developed and used it may be stated there are a number of forms of airplane antenna which offer considerable promise of complying with the radiation requirement and at the same time offer practically no interference with the movements of the airplane.

The tactical uses of the airplane wireless telephone called for transmission and reception on certain airplanes and for reception only on other airplanes. The apparatus developed therefore included two distinct types, one including both the transmitting and receiving elements mounted in a single box, as shown in Fig. 4, while the other included only the receiving element as shown in Figs. 5 and 6. The complete equipment comprising the transmitting and receiving set is shown in Fig. 7. The complete equipment comprising the receiving set only is different with respect to the power plant, which in this case consists of a 4-volt storage battery. This figure shows two telephone transmitters and two helmets, which are used in connection with an interphone system provided as an auxiliary to the wireless telephone. This interphone system enables two persons in the same airplane to converse with each other by ordinary telephone, and furnishes in itself a valuable communication system entirely exterior to the wireless telephone apparatus.

Where communication between an airplane and a ground station is desired this communication is effected by means of a special ground set which has been developed to correspond with the range and wave-length requirements of the airplane apparatus.

In using the apparatus above described, the only manipulation required of the aviator is switching from the transmitting to the receiving apparatus, or *vice versa*, as required. Ranges of several miles between planes are easily accomplished and under extremely favorable conditions much greater distances have been covered.

NEW TYPE OF APPARATUS.

Experience in the operation of the above type of wireless telephone apparatus indicated the desirability of certain improvements, particularly along the following lines:

Reduction in the size of the apparatus units to better adapt them to installation in the restricted space available on certain types of airplanes.

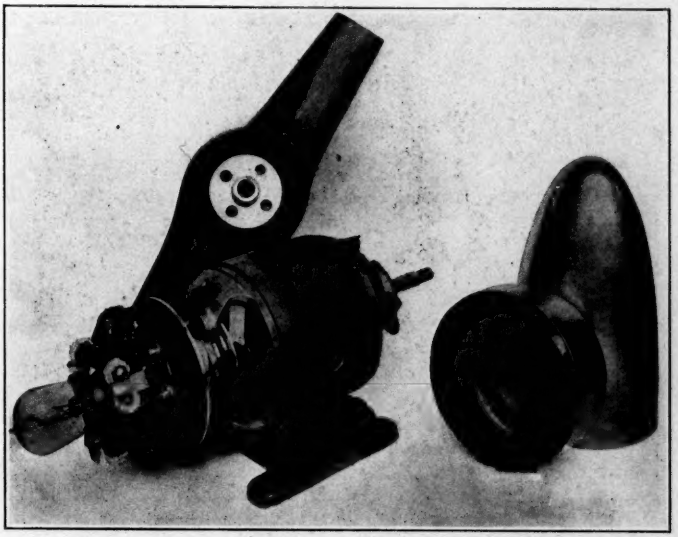


FIG. 1B.—WIND-DRIVEN GENERATOR, FAN AND REGULATOR TUBE.

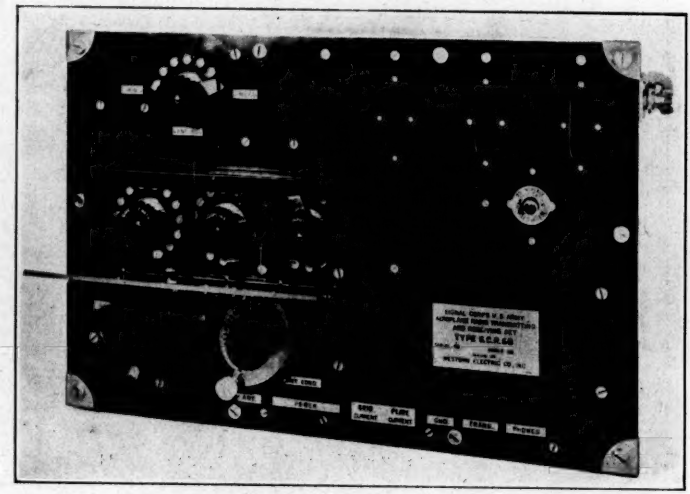


FIG. 4.—TRANSMITTING AND RECEIVING UNIT.

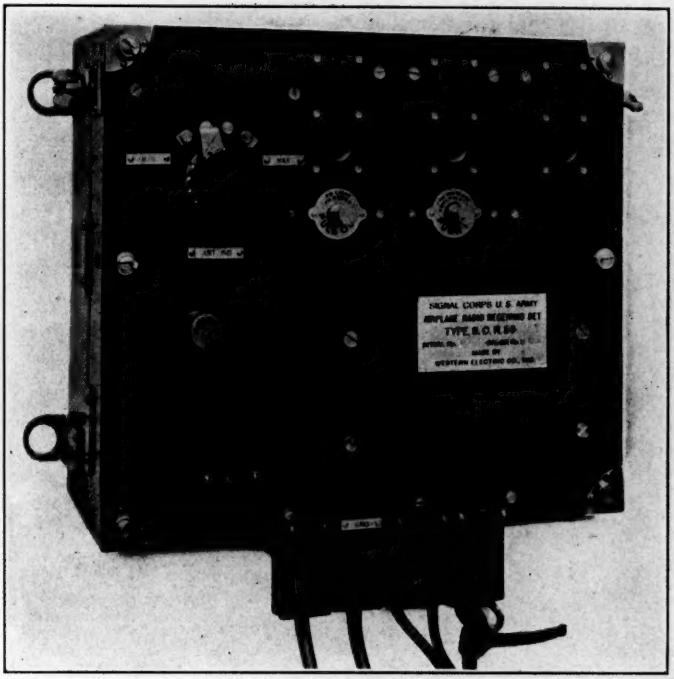


FIG. 5.—RECEIVING UNIT.

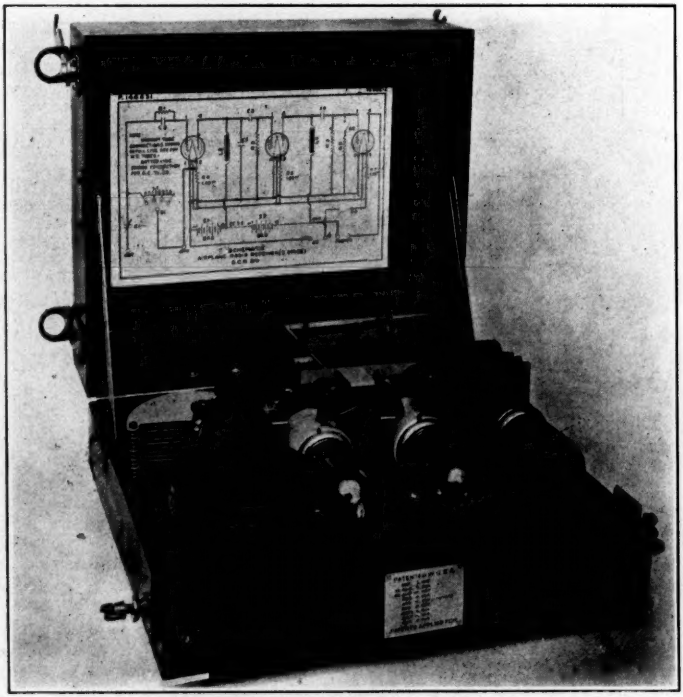


FIG. 6.—RECEIVING UNIT (OPEN).

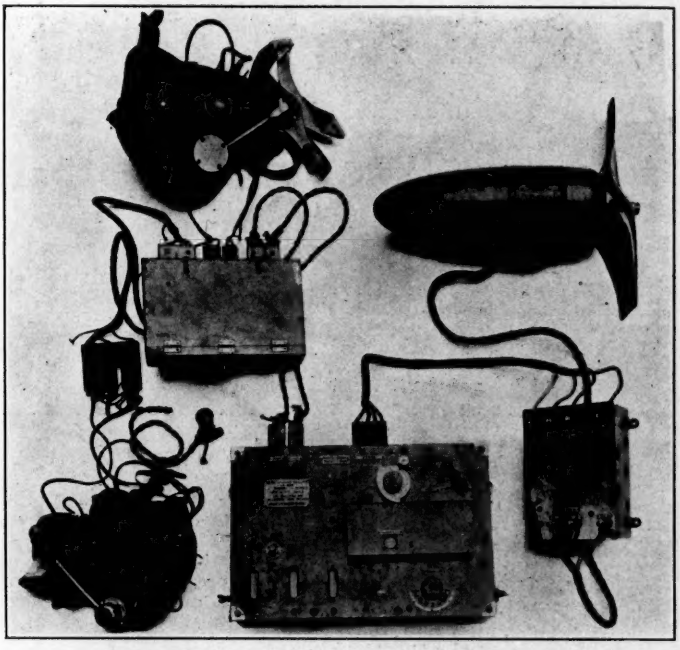


FIG. 7.—COMPLETE TRANSMITTING AND RECEIVING SET.

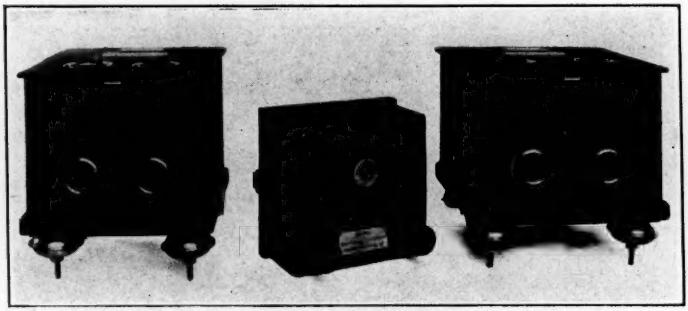


FIG. 8.—NEW TYPE OF AIRPLANE WIRELESS TELEPHONE.

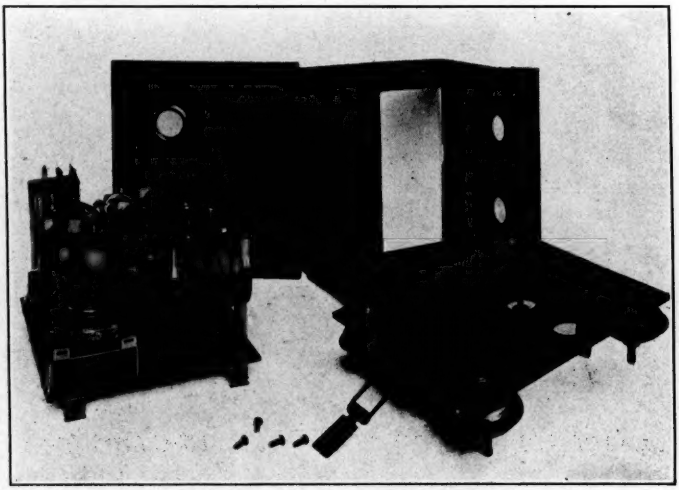


FIG. 9.—TRANSMITTING UNIT ALONE.

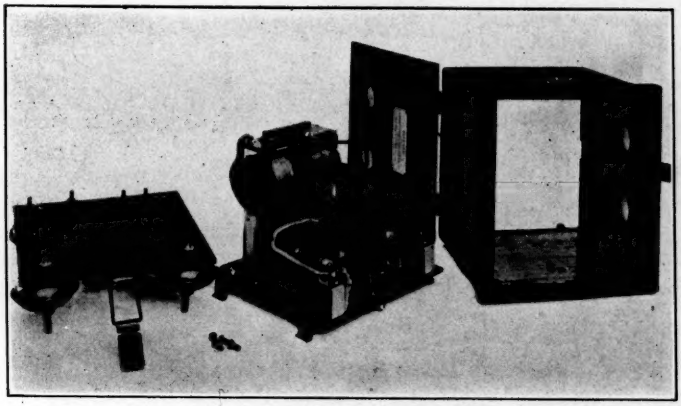


FIG. 10.—RECEIVING UNIT ALONE.

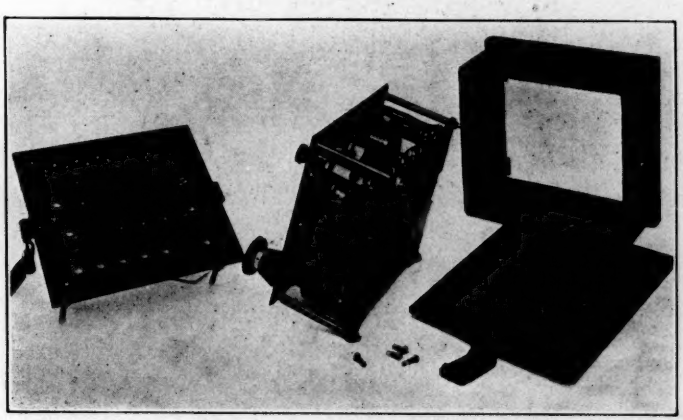


FIG. 11.—CONTROL UNIT ALONE.

Use of a very much shorter wave-lengths to make possible the substitution of antennæ which would not interfere with the use of the airplane and which would likewise reduce the amount of radio interference which would be experienced on the Western Front.

Accordingly, a new type of set was developed during the summer of 1918, the essential elements of which are illustrated in Figs. 8, 9, 10 and 11. Practical trials of this equipment have not proceeded sufficiently to indicate the superiority of this set from the standpoint of its use by the aviator. Its superiority, however, from the standpoint of installation is self-evident.

WIRELESS VS. WIRE TELEPHONY.

Any prophecy as to the future of the wireless telephone art should take due account of fundamental differences between wire and wireless telephony. While it is conceivable—though not probable—that improvements in directive radiation may be evolved which will cause the greater part of the waves radiated from a wireless station to choose a particular path, rather than to be spread broadcast as at present, there will always be a far more definite and restricted path for wire telephone signals than for wireless signals. As a result, it may be safely predicted that wireless telephony is not apt to supersede wire telephony in any of the fields now occupied by the latter. The application of wireless telephony to new fields, where wire telephony is either impossible or impractical from economic considerations, will furnish abundant opportunity for service of the greatest value. A combination of wire and wireless telephony, each in its own field, may result ultimately in a telephone system covering the civilized world.

COMMERCIAL FIELD.

To the average person the most interesting commercial application of wireless telephony is transoceanic, such as is suggested by the long-distance experiments mentioned above. While the scientific aspects of the question are such that the development of suitable apparatus for effecting reliable commercial service between such points as New York and London is a comparatively simple matter, economic questions have up to the present prevented serious consideration of such a project. It is entirely conceivable that improvements in the art may soon bring the cost of such a system well within the limits imposed by economic considerations.

Wireless telephony between ships at sea or between a ship and a shore station is a logical supplement to the wireless telegraph service now furnished on practically all ocean-going steamships. In this case, as in the case of transoceanic telephony, economic considerations are apt to retard the extension of this field until the development of apparatus less expensive than present types.

In the field of aviation, however, wireless telephony presents a number of advantages which it is believed will result in its rapid adaptation to the needs of this service. Entirely aside from the popular interest attached to telephone communication between different airplanes, or between an airplane and a ground station, the practical value, particularly of the latter, is sufficient in many cases to justify the required expenditure to provide this facility.

There are various special fields not included in the above which may call for the use of wireless telephony, such as communication between various islands of a group—for example, the Hawaiian Islands—the wire-

less telephone furnishing in this case trunk lines for tying together the telephone exchanges on the various islands.

MILITARY FIELD.

The use of wireless telephone apparatus in combatant military operations during the war was practically negligible. This should, however, not be interpreted as an indication that wireless telephony offers no advantages for military purposes, but rather that the training of personnel in its use had not proceeded sufficiently to warrant its use. Communications within various units of an army frequently call for extreme mobility of the apparatus. The prevailing method of establishing intermittent communication between temporary stations joined by wires laid on the ground is obviously far from ideal. If wireless telephone apparatus can be developed by means of which different centers of command can be kept in constant touch with each other while all are in motion the advantages of such communication will compel its adoption and wide use throughout the communication system of the Army.

In naval operations the use of wireless telegraphy is so widespread that it forms an indispensable link in the naval communications system. For certain kinds of service the advantages offered by telephony as compared with telegraphy make it extremely desirable that wireless telephone apparatus be developed to meet the requirements. The present state of the art indicates the certainty that this can be done.

In the field of military aviation wireless telephony finds its greatest present opportunity for immediate service. The requirements of inter-airplane communication are such that the telephone is peculiarly adapted. The use of wireless telephony within an airplane squadron at once makes possible the development of the squadron into a military unit wherein the various members are subject to the command of the leader in exactly the same way as military units on land and water. The development of airplane squadron tactics is therefore made entirely possible, whereas without the telephone it is considered that the difficulties of communication between various airplanes would have made such a development impossible. Communication between airplanes and ground stations comprises an equally important phase of the operation of military aircraft. Hitherto these communications have been chiefly those for directing artillery fire and the wireless telegraph has served this purpose reasonably well. The availability of the wireless telephone, however, will open up new possibilities in the use of airplane to ground communication, an example of which is furnished by the present operations on the Mexican border. Scouting parties, accompanied by airplanes, traverse the extremely mountainous country, with airplanes preceding the land forces and at intervals reporting their observations. If we imagine each of the scouting parties to be equipped with receiving apparatus sufficiently portable so that it does not in any way interfere with the movements of the party, it is at once evident that they could, without delay, be kept informed of the observations of the aviator, by direct telephone communication. This extension of range of vision would be of immeasurable value.

Developments which have occurred during the war period, while essentially of a military character, are immediately applicable to both military and commercial needs. These developments point the way to further progress in the art which it is believed will, within a short time, establish wireless telephony as an important element in many phases of our military and commercial activities.—"Journal of The Franklin Institute."

THE UNITED STATES NAVAL COMMUNICATION SERVICE.*

By Captain S. W. Bryant, U. S. N.

Acting Director, Naval Communication Service, Navy Department.

Mr. Chairman and Gentlemen: I am sure that you will regret to know that Admiral Bullard, who was to deliver this lecture, is unable to do so on account of absence on duty in France; and as he has delegated me to substitute for him, I shall do the best I can to outline the activities of the Naval Communication Service.

The practical use of radiotelegraphy for communication with vessels at sea, in the development of which the United States Navy was one of the pioneers, resulted in the erection and operation, by the Navy, of a chain of stations along the coasts of the United States for communicating with Naval and merchant vessels. For several years the development was restricted mainly to material features with the result that no progress was made toward utilizing the radio facilities that were available in a well-thought-out plan, except, of course, for tactical uses in the Atlantic Fleet where its development was fostered and great improvements were made in the fleet itself so far as related to the tactical operation of naval units. There were a number of coast stations which, individually, were excellent so far as range and operation were concerned, but we had no organization to co-ordinate their operation with that of the fleet.

In 1912 the so-called Naval Radio Service was established, with Captain Bullard as the first superintendent. It was apparent that the material progress made in radio was at that time much further advanced than the administrative and operating features, so that efforts were concentrated immediately on a plan for the establishment of a service of communication that would serve the needs of our fleets and merchant marine to best advantage, both in time of war and in time of peace. We had a number of stations along our coast that were individually very good, and materially good, and, so far as their operation was concerned, were very good; but they were not connected up in such a way as to serve the interests of the fleet to the best advantage.

The plan outlined provided for continuous communication with our fleets and among the various sub-divisions of the fleets, as well as for the co-ordination of all naval communication facilities so as to provide a rapid and reliable interchange of information between all naval organizations afloat and ashore.

The advisability of combining all naval communication activities—that is, telegraph, telephone, cable, etc., and radio—under one head was soon appreciated by the Navy Department, and the name of this office of the department was changed from the "Naval Radio Service" to the "Naval Communication Service," and it was placed under the Chief of Naval Operations where, logically, it belonged. It consists of three main divisions, *viz.*, Atlantic, Pacific and Philippines, and each division is subdivided into districts.

The Director of Naval Communications exercises his authority through the division heads (coast superintendents), who, in turn, direct the district superintendents. So far as is practicable, the communication districts coincide with the naval districts, and all matters of an administrative nature within a district are handled through the Commandant of the district, to whom the district communication superintendent is directly responsible for the operation and administration of naval communications within the district.

* Presented at a joint meeting of the Institute and the Philadelphia Section, American Institute of Electrical Engineers, held Wednesday, October 15, 1919.

The distribution of orders or instructions and the dissemination of information from the Navy Department, or from the heads of the various naval units, is thus provided for automatically. As an illustration of how this works, it is only necessary for the Secretary of the Navy to write one message, and if he wishes the entire naval service to receive it, that is automatically taken care of by the Communication Service. Each distributing office knows to whom it should send this message and from whom to expect acknowledgment. The acknowledgments are gathered in to the coast superintendents, and eventually to the communication office in Washington, and the acknowledgment is delivered directly to the Secretary. This same procedure may be followed by the commander of any naval unit for the distribution of messages through his forces.

I want to call your attention especially to the importance that other countries have attached to communications, because we feel that the people in the United States do not appreciate the importance of a satisfactory system of American world-wide communications; certainly not so much as is done in foreign countries. The British have two routes to the East by radio in addition to their cables running out through the Mediterranean. The Dutch have undertaken a very elaborate program. They hope to have their radio station on the Island of Curacao communicate across to the Dutch East Indies. The French have also elaborated their plans, and the Belgians have in process of erection a radio station in Belgium that will communicate direct with the United States and with their possessions in the Belgian Congo. This, of course, is in addition to the cables that are largely controlled by the various countries. England has been especially active in extending her communications, and wherever her communications go trade follows.

A very valuable experiment was carried out by the Navy Department in May, 1916, in which all the naval stations within the continental limits of the United States were connected up to a central telephone switchboard in the Navy Department, and by means of which instant telephonic communication could be had between the various naval stations and the Navy Department, and also among the stations themselves. This was made possible through the assistance of the American Telephone and Telegraph Company, and its value later on, when this country declared war against Germany, was clearly proven. It was during this test that the Commandant of the Navy Yard, Mare Island, California, talked by telephone to the commanding officer of the battleship *New Hampshire*, which was then at sea off the Virginia Capes. The Commandant's remarks came by long-distance telephone from Mare Island to Arlington, where the transmitting station was installed, and from there out to the *New Hampshire* off the Virginia Capes. The greatest value derived from this experiment, aside from the knowledge that such rapid communication by telephone was available to the Navy Department, was the fact that all of the apparatus necessary was specially marked and could be placed in operating condition on twenty-four hours' notice. As a result, the interior communications of the country, so far as naval needs were concerned, were, on the outbreak of war, in excellent operating condition, and made the task of the Navy Department, in communicating its instructions and orders to the various naval stations, a comparatively simple one at the time of the declaration of war.

We have one cable running from the United States direct to the continent of Europe that does not touch foreign soil between the United States and the European country, and that is a direct French cable from Cape Cod to France. All other cables touch in British territory or in the Azores. In the Pacific—we have one cable to the Philippines—all American; but the British have a cable running down from Vancouver to Australia by way of the Fanning Islands. The communication situa-

tion in the Pacific is a very serious one. The British control the cables on the east coast of Brazil from Buenos Aires up north. The Americans control them on the west coast and across to Buenos Aires. Every British possession practically is connected by some means of rapid communication with the mother country.

On January 1, 1917, the Naval Communication Service operated fifty-five radio stations, distributed along the coast of the United States and its possessions. Naval vessels were equipped so that they could receive only one message at a time. Not all of the American merchant vessels were equipped with radio apparatus, some were equipped with poorly designed radio apparatus, and none of their radio operators was proficient in the procedure of communications during war. The Navy had only 1,031 radio operators in its service.

The radio technical equipment of the Navy was as good as any in general use in the United States at the time, but the demands for communication proved that the technical equipment would have to be increased and improved to conduct all of the necessary communication demanded in time of war.

At the beginning of the war the demands for quick communication increased by leaps and bounds. It was found necessary to communicate with ships in all parts of the world, while at the same time to maintain long-distance communications between the Navy Department and our outlying possessions and expeditionary forces. It was necessary to maintain continuous and rapid communication between the Navy Department and Europe, South America, Central America, West Indies, Pacific Coast, Hawaiian Islands, Guam, Tutuila, and the Far East. The most important centers of communications were at Cavite, P. I.; Hawaiian Islands, Canal Zone, Washington, D. C., and the capitals of the Allied nations in Europe.

To meet the demands for communication, the Navy's facilities were greatly and rapidly increased, and means were provided for collecting and disseminating information to every part of our coast and to naval vessels in Europe, South America, and the Far East.

The Navy took over and operated fifty-nine commercial stations. At the same time the several privately owned stations were closed, including all the stations operated by the amateurs, which were not necessary nor desirable for use during the war. Sixty-seven land radio stations were built by the Navy during the war, all equipped with the best apparatus, thus more than doubling its radio facilities on shore.

Naval vessels were equipped with improved apparatus, so that when the armistice was signed, battleships were able to receive four messages simultaneously and transmit three. The Commander-in-Chief of the fleet could talk to the captains of vessels in the fleet; while, at the same time, the various ships of the fleet could communicate with one another. In addition, and at the same time, airplanes could communicate with their respective battleship units. None but a naval officer can appreciate the value of such a system or how much such a system facilitated the freedom of movement of the fleet.

The Navy Department equipped all American merchant vessels with modern apparatus and furnished operators for them, so that these merchant ships could receive messages at any time of the day and transmit messages at long distances in case of distress.

The Navy had to train most of its radio men because the radio amateurs in this country were soon incorporated in the army and navy. These operators were trained at Harvard. In June, 1917, there were 350 students under instruction. When the armistice was signed there were 3,400 men under instruction, and operators were being graduated at the rate of about 200 a week. A total of about 7,000 operators completed their

training. In addition to the radio operators, it was necessary to train officers for communication duties on board the ships. At the time the armistice was signed, each ship of the Navy had a communication officer, and each merchant ship had a chief petty officer who performed communication duties and, therefore, relieved the master of the ship from a very vexatious duty.

The year before the war there was handled approximately 125,000 dispatches from the Navy Department. These dispatches averaged about 25 words each.

From April 6, 1918, to April 6, 1919, approximately 1,000,000 dispatches, of an average of about 30 words each, were handled from the Navy Department alone. Some of these dispatches, on account of the necessity of broad-casting, were sent twice in order to insure their delivery.

As it was assumed that the use of radio apparatus by ships at sea enabled German submarines to ascertain more or less accurately the movements of such ships, communication by radio from merchant ships was discontinued except in case of emergency. Men-of-war were cautioned not to use their radio apparatus unless necessary. However, it was very necessary that information should be received on shore regarding the movements of the enemy, and that the consequent orders to ships at sea should be transmitted expeditiously. Therefore, in order to direct the movements of convoys, and to transmit information to naval vessels regarding the enemy, and to issue orders to both merchant ships and naval vessels, a comprehensive system of transmission from shore was organized with the view of making it unnecessary for ships at sea to use their radio apparatus.

All merchant vessels listened for their orders from certain designated shore stations during certain hours of the day. These messages were sent by high-power and low-power stations, depending on the distance of the ship from shore. Naval vessels intercepted messages from shore stations at all hours of the day. In order to send a message to a naval vessel at sea, it was necessary only to transmit from certain shore stations on a designated wave-length. It soon became evident that this was a very sure means of communication. Many times, fifty or sixty messages were transmitted to sea simulatneously, all destined for different classes of vessels, and they were received by ships in accordance with the plan.

The foregoing system demonstrated that ships at sea could be warned of mines and submarines, and their movements directed without the necessity of their using their own radio apparatus. The system was automatic to such an extent that it was almost certain that a vessel could be reached at any time.

In order that errors in this system might be eliminated and in order that the Navy Department might be informed of the movements of vessels, there was established a Shipping Information Service. A confidential bulletin was published showing the movements of all United States vessels and as many foreign vessels as could be obtained. This information was collected from all the important ports of the world and the data printed in a booklet. This service grew to such an extent that the booklet now contains the names of approximately 12,000 vessels, their arrivals and departures, character of cargo, and destinations, and is of much value to shipping and business interests. It is the present plan to have the Naval Communication Service continue this publication until Congress makes other disposition for its publication.

In order to check the radio work of merchant vessels, a comprehensive system of inspection was organized, both in the United States and abroad. Every merchant vessel that came into port received a thorough inspection of its radio apparatus, and the radio operators were examined and thoroughly instructed. Any mistake indicated in the log-books was investigated

and the operator instructed as to the correct method of handling such cases.

Besides inspections, the Navy maintained a comprehensive system both at home and abroad of radio repair stations. Any radio apparatus on board ship which had broken down was repaired when the ship came to port.

It soon became evident that if the commander of the United States forces in Europe was to maintain close touch with all of his forces, it would be necessary to establish and control a complete system in Europe. To this end cables were laid and land wires and radio stations constructed in France, England and in Italy. The Navy used a great many of these land wires and cables that were constructed by the Signal Corps of the Army. Close co-operation was maintained with the Allied communication services with the view of utilizing their systems whenever possible and with the view of avoiding duplication of effort.

During the war it was found necessary to maintain radio communication between the United States and our naval and military forces in Europe and in other parts of the world. In October, 1917, the Allied military and naval officials had a conference to determine the best methods of operations that were to be used in maintaining communication between the United States and Europe in case the cables were either cut by the enemy or otherwise placed out of commission.

It was decided that the United States would use the radio stations at New Brunswick, Annapolis, Tuckerton and Sayville for transmission purposes; but at this time none of these stations was in reliable communication with Europe at all times of the day and year. Therefore, it was necessary to increase the power of Tuckerton and Sayville and to place more modern apparatus in New Brunswick. The radio station at Annapolis had not been completed, and orders were given to rush the construction. There were only two transatlantic receiving stations, *viz.*, one at Chatham, Mass., and one at Belmar, N. J.

In Europe the only radio stations available for use in transoceanic communication were those at Rome, Italy; Lyons, France, and Carnarvon, Wales. Of these stations, the one at Lyons, France, was the only one able to communicate satisfactorily with the United States.

None of these stations was equipped with high-speed apparatus, and none was equipped in such a way as to avoid intentional interference from radio stations in Germany and the systems of operation and control were not such that large volumes of traffic could be handled.

At first it was decided that all messages from Europe destined to the United States would be sent during certain hours of the day from Lyons, and if possible from Rome and Carnarvon. Messages from the United States destined for Europe were to be transmitted from New Brunswick, Sayville, Tuckerton, and as soon as possible from Annapolis during the remaining hours of the day. In the beginning this system was capable of handling only a comparatively few important messages. Later, when it became evident that the Germans were making some attempt to cut cables off the coast of the United States, it was decided to erect another high-power station in France. In the meantime, improvements were being made at Lyons and Rome. The key was in the Navy Department for transmission from Sayville, Tuckerton, New Brunswick and Annapolis.

New improvements in organization and operating methods were made both in the United States and in Europe, resulting in a centralized control of four United States high-power radio stations from the Navy Department. A receiving station was constructed at Bar Harbor, Maine, which proved to be one of the best receiving stations in the United States. The receiving stations at Chatham and Belmar were not used, as they were not necessary. The power of the radio stations at Tuckerton, Sayville and

New Brunswick had been increased. At the time the armistice was signed, the United States system was capable of handling several thousand words per hour, and the whole transoceanic system was able to transmit and receive messages simultaneously without fear of intentional interference from Germany's high-power radio stations. Also, just before the armistice was signed, experiments in high-speed transmitting and photographic reception had begun. Had it been necessary, the transatlantic radio service would have been capable of handling all of the Government traffic between Europe and the United States.

When the United States entered the war it was noticed that the Central Powers were conducting a comprehensive scheme of propaganda by wireless. Counteracting this were the systems operating from France and England. The United States had no means of distributing American news throughout the world. Therefore, it was decided to use the transoceanic system of the Navy to distribute news of a reliable nature from the United States. The transatlantic stations transmitted this press news to Europe and South America. Naval vessels in South America received the press and distributed it to the local papers in those countries. The European news was distributed by Admiral Sims' headquarters and redistributed to the various capitals of Europe, including points in Russia. The Central American news was broadcasted from the Navy's high-power station in the Canal Zone, and was received in the northern part of South America and Central America and Mexico. News was distributed to the Philippines, Japan, China and Siberia, through the Navy's transpacific high-power stations. These reports were received in the Philippines, Shanghai, Vladivostok and Japan, and distributed to the local papers in those countries.

During the war it was found exceedingly difficult to locate persons in the United States who were using radio apparatus unlawfully. Also, when the German submarines began operations off the United States in June, 1918, it was found that, although the radio signals of the submarines were intercepted by naval radio stations along the coast, there were no efficient devices by which the exact location of the submarines could be ascertained from their radio signals.

It was found that enemy submarines used their radio apparatus promiscuously, and that they operated in pairs in order that they could fix the position of their prey by means of bearings. Such procedure necessitated the use of radio.

In order to counteract the foregoing situation, the Navy developed a comprehensive system of radio compasses, by means of which the bearing or direction of the enemy's signals could be obtained. Also, all signals were copied so that every time a message was sent the Navy could trace it. Shortly afterwards, it was noted that the submarines did not use their radio, and it is believed that the Navy's shore radio compass system robbed the enemy of a vital weapon, as the radio compass not only made it dangerous for the enemy to use their radio for communication purposes between one another, but also prevented them from using it for sending decoy distress messages.

Later the Secretary of the Navy "in a plan to hasten the progress of troopships" authorized the construction of fifteen additional radio compass stations, making a total of thirty-four on the Atlantic and Gulf Coasts. These radio compass stations were at harbor entrances and enabled ships at sea to enter port without consequent delays due to thick weather and fog. This was a very important item in the war as every minute counted in a ship's voyage.

After the armistice was signed, the Secretary authorized the construction of twenty-four more radio compass stations, which made a grand

total of fifty-eight in the United States, and which are to be used as aids to navigation during time of peace.

The technical bureaus of the Navy Department kept pace with the operating departments in their advance in the art of radio communication and in co-operation with the radio engineers of the country accomplished some remarkable developments in radio during the war.

Efficiency in high-power transmission was increased from 30 to 90 per cent. Not only was greater efficiency arrived at with lower cost, but the power of transmission was increased. For example, the radio station at Bordeaux, France, which is being constructed under the auspices of the Navy Department, has an input of 1,000 kilowatts. Its range is estimated to be 12,000 miles. It has eight 820-foot towers.

There was an increase in speed of transmission from about 30 words a minute to 100 words a minute in actual practice, and to about 300 words a minute in prearranged tests. One of the difficulties in high-power stations was the sleet on the antennæ. Methods have been arrived at by which sleet is now prevented from accumulating on the wires of the antennæ.

The valve has been developed from a non-oscillating detector to an oscillating transmitter. It is possible to receive radio signals by the beat method and to transmit signals from the valves at comparatively long distances. The valve is used also in the transmission of speech, and is very efficient for this purpose.

Another feature of valve transmission is that it permits of very sharp tuning, which in turn permits simultaneous transmissions from a great many stations. It is believed that it will be developed in the future to such an extent that it will replace most of the existing low-power transmitters.

Another feature of the valve is that its life has increased from 5 hours to over 5,000 hours, which is a very important item in the expense.

Great improvements have been made in receiving apparatus in that they are more selective, and directive receiving has increased in efficiency from 0 to 75 per cent. The old type of overhead antenna is being rapidly replaced by the use of balanced loops and underground wires, radio phase changers, and low horizontal wiring.

It is now possible to receive signals on submarines while submerged at depths of 20 feet, from shore stations, aircraft overhead, and ships afloat. This system was used to advantage in directing our submarines off our coast when they were hunting for enemy submarines.

Another improvement has been made in the radio compass, which was used at first for detecting the positions of enemy submarines, but is now developed into an aid for navigation. With properly trained personnel, the Navy is now able to give ships their positions without any large error. This will be a great boon to our merchant marine because it eliminates the delays caused by fog and thick weather, besides making navigation generally more safe along the coast.

An interesting experiment was carried on in San Francisco from the naval station at Goat Island during a recent visit of the Pacific Fleet to that port. A radio telephone was installed on Goat Island, in San Francisco Harbor, and connected by land wire to the telephone company's switchboard in San Francisco. A man on board ship was thus able to talk to his friends on shore in any part of the city. Also, this friend on shore could call up the ship from his home. This means of communication with the fleet became a popular fad in San Francisco during the stay of the fleet.

The foregoing developments are just an indication of the possibilities of the use of radio communication in the future.

If the general public of the United States is to receive the best sort of service in radio communication, it will be necessary for some central controlling agency to regulate the matter. There are so many different private services that naturally wish to have radio communication that the only solution is to have it regulated by some central authoritative agency. For example, we have heard that a man in Waco, Texas, desires to build a radio station to communicate with another radio station in Boston. This service is for his private use. Another man desires to communicate between Detroit, Mich., and Los Angeles, California. This is also a private service. Another man wishes to communicate between Philadelphia and New York. This is a private service. Another man wishes to communicate between Chicago and St. Louis. This is a private service. Multiplicity of such private service will soon demonstrate to the public that the best use of radio communication is being handicapped. The man who has the circuit from Waco, Texas, to Boston may receive interference from the man who has a circuit from Detroit to Los Angeles. The man who has the service from Chicago to St. Louis may receive interference from the man who has a service from Detroit to Los Angeles. Unless there is some central regulating body which has the power to regulate the use of radio in accordance with the development of the art, it is believed that the future demand for radio communication will be limited, and in consequence the art will not progress as much as it would if it were properly fostered and regulated. The extensive use of radio in European countries by the Allied armies and navies with the consequent experience gained has demonstrated this fact.

To illustrate how a naval communication district acts, I should like to take as an example the Third Naval District, which extends from Rhode Island to Barnegat Inlet, and in which there are eight coastal radio stations which are located as follows: Montauk, L. I.; Fire Island, L. I.; Rockaway Beach, L. I.; Sea Gate, N. Y.; Bush Terminal, N. Y.; Navy Yard, N. Y.; Mantoloking, N. J., and New London, Conn. There are also five radio compass stations located as follows: Montauk Point, L. I.; Fire Island, L. I.; Rockaway Beach, L. I.; Sandy Hook, N. J., and Mantoloking, N. J. These radio and compass stations are all controlled from one Central Control Station, located at No. 44 Whitehall Street, New York City, at which place are also the offices of the District Communication Superintendent. Direct wires from each of these stations lead into the Central Control Station, and by means of a plug-board arrangement similar in type to that used by the telephone companies, any one of these stations may be used as a transmitter by the operator on watch at the control station.

The control station is divided into a number of booths which are magnetically shielded from one another and which contain receiving apparatus of the most up-to-date type. Each booth is given a wave-length which the operator on watch must guard. There is no transmitting apparatus at this control station, all transmitting being done by means of distant control through one of the other stations mentioned above. Therefore, if the operator on watch at 600 meters receives a call and desires to answer, he promptly plugs in on a wire to any station he may decide to use and transmits via that station. He is listening all the time to what he is sending and should he hear a distress signal, he could instantly stop and give his attention to the distress call.

A chief electrician (radio) is on duty at this control station as supervisor of traffic. On his desk he has a receiver which enables him to listen in and keep check on the traffic being handled on the various wave-lengths, and, from time to time, gives orders to the various operators and stations so as to avoid interference. Such a system of supervision was found necessary in order to overcome some of the difficulties brought about

by the large increase in radio traffic about the port of New York. The excellent manner in which this system functions locally about the port of New York is another illustration of the necessity of radio supervision by one central controlling agency.

All the stations in the Third Naval District, however, are not at all times controlled from the Central Control Station. If traffic warrants it, some outlying station, such as Montauk or Fire Island, is given orders by the supervising electrician to handle traffic independently. At such times, the outlying stations are practically acting as agents for the control station.

The great advantage, besides regulating radio traffic and cutting down the amount of interference, is that should any of the stations in the district, or the control station, hear a distress call, or any other emergency arises, the control station can immediately notify all stations to stop sending, which will leave the air clear so that the emergency may be taken care of. The ability to stop all stations in the district instantly is an absolute necessity in time of war and proved itself of much value during the time the German submarines were active along the American coast.

The radio compass stations are controlled in a manner similar to the radio transmitting stations in the Third Naval District. Each compass station in the district is connected with the Compass Control Station at No. 44 Whitehall Street, New York City (which is in the same room with the Radio Control Station) by means of direct wires. The compass stations are not equipped with transmitters, and, therefore, never work independently of the Control Station, but forward all their bearings to the supervising operator. The procedure followed by a vessel which desires her position is as follows:

The vessel calls "NAH," the call letters of Navy Radio New York, signing off with the ship's call letters, followed by the international radio abbreviation "QTE," meaning, "What is my true bearing?" or with "QTF," meaning, "What is my position?" When this signal is heard by the radio operator on watch, the compass supervisor is immediately informed and he, by means of a master key which controls all wire circuits to the compass stations simultaneously, notifies the compass stations that the ship is calling for bearings and gives the wave-length by which the ship will transmit. The radio operator in the meanwhile has acknowledged the ship's call and instructed the ship to transmit by sending dashes on whatever wave-length he may specify. The compass supervisor, who also listens in to the radio signals, gives a signal on the wires leading to the stations when the ship commences to send dashes, or, in other words, tells all stations, "There he is now." All five stations in the district then take bearings on the ship which is transmitting, and when the supervisor calls for same, forward them to the Control Station on the wire. The supervising operator enters upon a specially prepared radio blank the bearings obtained, and before transmitting these bearings to the vessel plots them on a chart specially prepared for this purpose, noting whether a good fix was obtained. If the bearings obtained were good, he turns over the radio blank with bearings on it to one of the radio operators, who, in turn, transmits it to the vessel. If the bearings obtained are poor, as shown by plotting them on the chart, the compass supervisor informs the radio operators, who request the vessel to repeat, in order that a new set of bearings may be obtained.

The average time required to obtain the bearings and forward them to a vessel is between three and four minutes. In thick weather there are many calls for radio bearings, and the five stations in the Third Naval District are kept busy. It is always the desire of the supervising compass operator to obtain bearings from as many stations as possible, in order to note whether they all check. If bearings can be obtained from three or

four stations and these bearings all intersect at one point, he is then reasonably certain that the bearings obtained are accurate.

A means of checking radio compass stations has been devised in the Third Naval District and placed in operation there. By close co-operation with the Navy Route Office, Custom House, New York, where all masters of vessels call for information regarding shipping, much data has been obtained which has proven itself useful in compiling efficient curves and records of the behavior of the radio compass stations. This system has been developed in order to be able to tell at a glance how each station behaves and what the average error is in 20-degree sectors. It has been found that in some sectors the compass may read minus, while in another sector it may read normal or plus. With such data on hand it is comparatively easy to make tests and recalibrate stations, as it is already known in what directions and by how much the station is off. Such a system is especially valuable in view of the ease with which a radio compass may be influenced either by change in a position of the apparatus, slipping of the compass dial, or due to disturbing influences in the vicinity of the station, such as telephone wires, etc.

I just want to say a word in regard to the personnel employed at these radio compass stations. You have seen a photograph of the kind of place they have to perform their duties in, and most of the stations are in similar isolated places. In the winter time, especially, there is quite a strain on the operator, and they deserve much credit for the service they have rendered. They have to sit quietly in a small hut on some lonesome beach, listening continually for vessels on which to obtain bearings, in order that navigation may be made less dangerous and life and property at sea be safeguarded. One of the greatest drawbacks to the present radio compass installations is that so much depends upon the human element. What is badly needed, and which will undoubtedly be developed in the very near future, is an indicating instrument for use in connection with loops. When such an instrument has been devised, it will be quite simple and more accurate to obtain bearings on any radio station. At present very much depends upon the operator's acuteness of hearing and judgment, and as long as such is the case, absolutely perfect bearings cannot be guaranteed.

I want to call attention to the flexibility of the Naval Communication Service and cite as an instance the flight of the NC-4. A message was transmitted from the Navy Department to the plane during its transatlantic flight, a reply was received from the plane, and this reply was transmitted to London, Paris, San Francisco and the Canal Zone, and an acknowledgment received from those stations, all within three minutes of the time of beginning the first transmission to the plane from the Navy Department. Of course, every one was very much interested in the flight and the stations were all very keen to give the very best service, but this remarkably rapid operation was even a little better than we had anticipated.

During the Peace Conference the Naval Communication Service handled all of the radio communication for the American delegation. During the past summer, at the request of the American Relief Association, the commander of our naval forces in European waters put the Naval Communication Service personnel on land lines, handling the Relief Association messages throughout certain countries in Europe, and they are now handling that service and will continue to handle it until peace is finally proclaimed. This involves a complete communication system in central Europe, and gives the Navy, as well as the American Relief Association, a communication system between its London headquarters and Paris, Germany, Poland, Belgium, Italy, Austria-Hungary and Turkey.

The Communication Office of the Navy Department has handled during the last year the following messages:

Sent to Europe by Navy Department	16,910
Sent to Europe by other Departments	3,645
Sent to home waters by Operations	22,870
Sent to home waters by bureaus and other departments	351,516
Received from Europe by Navy Dept. for Navy	23,034
Received from Europe by Navy Dept. for other depts	3,893
Received from home waters to Operations	49,950
Received from home waters to bureaus and other depts	717,313
Total	794,190
Grand Total	1,189,131
Grand Total number words at 60 words per dispatch	71,347,860

The foregoing total was handled as follows:

By Costal Radio	1,621,542
By High Power Radio, Transatlantic and Continental	16,215,423
By Leased Wire, Western Union and Postal	53,500,895

The above figures are exact, except the Bureau dispatches, which are approximate and are based on the daily ratio of bureau dispatches to others during the last five months since an accurate record has been kept.

You will note that there were approximately 71,350,000 words handled by the Naval Communication Service. The high-power radio handled approximately 16,000,000. The leased wires handled approximately 53,000,000, and the coastal stations handled about 1,500,000.

During the period of demobilization a very large commercial business was done with returning transports, some of the larger transports handling fifteen hundred messages in a single month, the men wishing to send messages to their friends at home. In order to encourage this use of radio by returning troops, free service was accorded military personnel and civilian employees of the Government in so far as the ship's sending charges were concerned. Of course, this served to increase the traffic and afforded the men a chance to communicate with their families.

During the period of the war and until April 1, 1919, practically no revenue was obtained from traffic with foreign ships. This was due to the fact that up until that time no personal messages were allowed and Allied countries, with one exception, had agreed to handle messages for Allied ships free of cost as regards shore station tolls. Pre-war charges were placed in effect for United States shore stations on April 1, 1919, and foreign ships were charged regular shore station tolls.

Owing to the congestion of the Pacific cables, the Naval Communication Service reopened the transpacific circuit to Japan and the Philippines on December 19, 1918. This service, so far as Japan was concerned, took the place of the service inaugurated by the Marconi Company about three months previous to the outbreak of the war, the Navy carrying out the agreement as to tolls between San Francisco, Pearl Harbor, and Japan. Owing to the large volume of Government business this traffic was restricted to full-rate business only.

In November, 1918, the telegraph and telephone division was in charge of a lieutenant-commander, with five officers, twelve chief petty officers and an enlisted personnel of about one hundred and thirty. The telegraph system of the Navy Department at that time included wires from Galveston, Texas, to Bar Harbor, Maine. The leased telephone wires of the Navy Department extended from Norfolk, Virginia, to Portsmouth, N. H., there

being seven private telephones from the Department to New York alone. The telegraph office of the Navy Department was handling 4,000 messages a day and the Navy telephone exchange was handling 18,000 telephone calls per day.

At the time of the armistice, the Daily Shipping Bulletin, which I think I referred to previously, was being printed on a hand press and about 300 copies a day were being distributed. It was very roughly made up and had not assumed any permanent form. The personnel consisted of three officers and about 100 enlisted men.

By July 1, 1919, the circulation of the Daily Shipping Bulletin had grown to nearly 2,000 copies a day. It was being printed on a power press and had assumed a standard form. Of its total circulation nearly 1,400 were commercial firms, such as shipping companies, marine underwriters, ship brokers, exporters and importers, press associations, etc. The Bulletin contained the names of 12,500 ships with news of their latest movements and the record of nationality, register, tonnage and cargo. The popular demand for the Bulletin is growing daily and its success as a government activity is assured. Arrangements are under way to establish a permanent civil service personnel for the operation of the Bulletin to replace the enlisted personnel whose enlistments will expire or whose service in the reserve force will terminate.

The censorship of all cables was controlled from this office through the following branch offices:

	Personnel	
	Nov. 11, 1918	*June 30, 1919*
Brazil	9	0
Guam	5	0
Guantanamo Bay	3	0
Galveston	17	0
Honolulu	17	0
Cape Haitien	1	0
Key West	9	0
Lisbon	1	0
New Orleans	12	0
New York	760	78
Paris	1	0
Ponce	3	0
Panama	8	0
San Antonio	7	0
St. Croix		
Havana		
San Domingo and Puerta Plata	5	0
San Diego	1	0
San Juan	9	0
San Francisco	151	0
St. Thomas	3	0
Seattle	5	0
London	1	0
Chief Cable Censor	103	4

On April 18, 1919, by executive order, the censorship on all cables was removed from all messages except those addressed to or from German territory. This act greatly reduced the activities of the section and all branch offices except Washington and New York were closed. On July 23, 1919, all censorship of cables was removed and this section rapidly completed its most important duties.

In closing, I would like to say that we are trying to get the people in the United States to appreciate the value of communications, and we

feel that every foreign country of consequence—England, Germany, France, Italy, Belgium, and Holland—appreciate the great importance of communications and of having a system of communications over which they have control; but it seems that the people in this country have not fully realized the benefits to commerce that will naturally follow if we do have an efficient communication service with foreign countries, or such a service to those countries with which American commercial interests wish to do business.

In the Pacific, one of the most vital considerations at present is getting reliable news from the Far East into the United States, and from the United States into the Far East. The attitude in China toward Americans is one that could not be better; their feeling, as expressed to me by people who have recently been in China, is one of the deepest friendship for us, and the question of establishing communication with them and of getting reliable and recent news to and from China is one of the most important questions of the day, and I wish to emphasize the point that if there is any way of impressing upon every American the necessity for communications and the interest that the United States should take in it and in its development, and in fostering the development of high-power radio or cables, it is a patriotic duty to do so.—"Journal of the Franklin Institute."

THE ACCIDENT TO SUBMARINE *K. 13*.

Mr. Hillhouse's Account, released by the Admiralty, of the Accident in the Gareloch in January, 1917.

K. 13 was one of two vessels of the double-hull type ordered from the Fairfield Company late in 1915. She was noticeable on account of her size and method of propulsion, being over 330 feet in length, of 2,600 tons displacement, and fitted with water-tube boilers and steam turbines for surface propulsion. For underwater work she had the usual storage batteries and electric motors.

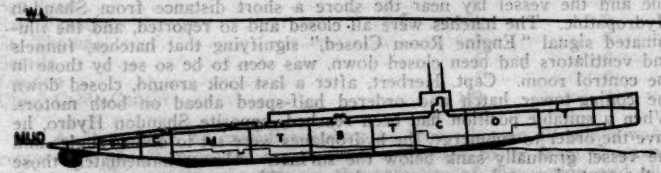
On Monday, January 29, 1917, she proceeded to Gareloch to carry out her acceptance trials and made a successful dive to 83 feet, remaining submerged for about two hours. The ship was duly accepted, but as the boiler room had been too hot during the dive to enable the watertightness of the funnel covers and boiler-room ventilators to be checked, another short dive of about a quarter of an hour's duration was asked for and decided upon.

On board at the time of diving there were 55 naval officers and ratings, 11 Admiralty and sub-contractors' men, and 14 Fairfield officials, standing-by only, the ship being worked entirely by her own crew. The day was fine and the vessel lay near the shore a short distance from Shandon Hydropathic. The hatches were all closed and so reported, and the illuminated signal "Engine Room Closed," signifying that hatches, funnels and ventilators had been closed down, was seen to be so set by those in the control room. Capt. Herbert, after a last look around, closed down the coning-tower hatch and ordered half-speed ahead on both motors. When a suitable position had been reached, opposite Shandon Hydro, he gave the order to submerge, the hydroplanes were set to diving angles and the vessel gradually sank below the surface. Almost immediately those in the control room became aware that something was wrong, as the depth gauges showed that the vessel was sinking much more rapidly than was intended. Orders were at once given to blow all tanks and come to the surface. In spite of this the vessel continued to sink rapidly. Mr. Hepworth, the Admiralty Boiler Overseer, was in the boiler-room passage when submergence began and, through the bull's-eye in the side of the

passage, saw water pouring into the boiler-room. Meantime, the depth gauges showed in quick succession 20 feet, 30 feet, 40 feet, 50 feet, and finally 55 feet, when the vessel came gently to rest on the bottom with a slight list to port and an inclination of about 4 degrees up by the bow. The actual depth was afterwards found to be 64 feet.

Stock could now be taken of our position. Repeated telephone calls to the engine-room met with no response and we feared the worst for our comrades in that portion of the ship. Luckily our batteries were fully charged. The compressors were run for a short time to reduce the air pressure in the hull and to relieve our ears. Our position appeared to be desperate and I do not think there were any on board who had more than the very faintest hope of ever seeing blue sky again. As it happened, the captain of *E. 50*, which was also in the Gareloch on diving trials, had been watching our dive and "did not like the look of it." He dropped a buoy to mark the spot and came over to meet the tender, *Comet*, which was returning to stand by and discussed the matter with Mr. Cleghorn, who had also become alarmed on account of the large quantity of air which had come up. Mr. Cleghorn immediately proceeded ashore and communicated by telephone to Fairfield and to the Captain Superintendent Clyde (Capt. Bryan Bartelott), and at once things were set going.

Shortly after settling down, we began to open the watertight doors again to obtain more room and more air. The watertight door leading to the submerged torpedo room was cautiously opened, releasing two men who had been shut in. The compartment was found to be practically free of water, though its after bulkhead, constructed to withstand a pressure of 15 pounds per square inch and now enduring nearly 25 pounds, was leaking freely and a considerable quantity of water was coming through the voice pipe, and the glands for cables, telegraph shafting, etc. Water was gaining at the rate of about 2 feet per hour in the amidships torpedo compartment and at intervals the electric bilge pump had to be run for short periods to eject this. For the 48 persons imprisoned in the forward portion of the ship the available air space was about 12,000 cubic feet, giving about 250 cubic feet of air per person, and unless the air could be renewed our allowance of oxygen would last only eight hours. We actually carried on for about 42 hours on what air we had. This we were able to do by drawing upon our compressed air supply, at the same time forcing some of the vitiated air back into other bottles by means of the air compressor. On Tuesday the air was so bad that a match when struck produced only a slight smoke, but no flame, and as the air in our submerged prison became more and more impregnated with carbonic acid, so did our breathing become more and more difficult and we had to inhale and exhale with painful rapidity.



POSITION OF "*K 13*" WHEN SHE GROUNDED.

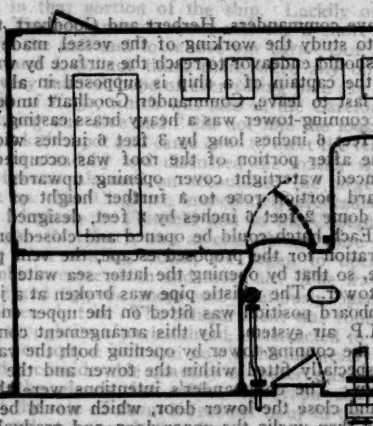
When day broke, on Tuesday morning, we could see a greenish light through the periscope. We raised the masts to indicate our position, but afterwards learned that they had not broken surface, though the top of the

fore mast was bent well over due to its having fouled one of the salvage vessels. About 8 o'clock we heard heavy footsteps and tappings on the outside of the hull. But so drugged were we by the bad air that we had become almost indifferent, and the knowledge that help was at hand roused no enthusiasm, not even a cheer. We tapped back again and tried to establish communication by means of the Morse code, but for some reason this did not go very well. The diver departed, and we had another long spell of waiting.

And now our two brave commanders, Herbert and Goodhart, the latter of the *K. 14*, on board to study the working of the vessel, made up their minds that one of them should endeavor to reach the surface by way of the conning-tower, and as the captain of a ship is supposed in all cases of abandonment to be the last to leave, Commander Goodhart undertook to make the attempt. The conning-tower was a heavy brass casting, elliptical in horizontal section, 5 feet 6 inches long by 3 feet 6 inches wide and 4 feet 6 inches high. The after portion of the roof was occupied by the exit hatch with a balanced watertight cover opening upwards into the chart-room. The forward portion rose to a further height of 3 feet 6 inches in the form of a dome 2 feet 6 inches by 2 feet, designed to carry the projector compass. Each hatch could be opened and closed only from its underside. In preparation for the proposed escape, the vent pipe was removed below the valve, so that by opening the latter sea water could be admitted to the conning-tower. The whistle pipe was broken at a joint and a valve taken from an inboard position was fitted on the upper end of the pipe leading from the H.P. air system. By this arrangement compressed air could be admitted to the conning-tower by opening both the valves described—the new valve specially fitted within the tower and the original valve in the control room. The commander's intentions were that both should enter the tower and close the lower door, which would be clipped from below. They would then unclip the upper door, and gradually flood the conning-tower, squeezing up the air in it until its pressure became equal to that due to the head of sea water upon the upper door. This, being balanced, the two occupants of the tower standing with their heads in the dome from which the air could not escape. The water in the conning-tower at this time would be about 3 feet deep, but as soon as the lid was raised, the air above this level and below the dome would, of course, escape and be replaced by an inrush of sea water. H.P. air was then to be turned on, and, aided by its outflow, Commander Goodhart was to pass through the upper door and endeavor to find his way through the chart room door and swim to the surface. As soon as he had gone, Herbert was to shut off the air supply, close and clip the outer door and knock loudly on the inner hull. This was to be the signal for those within board to open the drain valve and as soon as this was done Herbert could let a small amount of compressed air into the tower to take the place of the outflowing water. Those within board were to unclip and open the lower door and receive Herbert back into the vessel. A small tin cylinder was prepared to carry a message to the surface in case Commander Goodhart himself failed in his attempt. The cylinder was decked out with red bunting and Goodhart was to carry it in his hand and release it as soon as he could, clear of the wheelhouse.

It was a well laid scheme, but like many such it went agley. The two heroic commanders divested themselves of most of their clothing, entered the conning-tower and closed the lower door. Inboard, we clipped the door, opened the air valve and waited. Presently we heard a rumbling gurgling sound by which we knew that the outer hatch had been opened and air admitted. We anxiously waited for the noise of the air to be replaced by the prearranged thumping on our roof. But no signal came.

Reluctantly, we closed the air valve. We afterwards learned that the two commanders had opened the sea cock and had stood till the ice-cold water had reached their middles. Then the door was lifted, air turned on, Goodhart said, "Well, I'm off," and with Herbert's "Good luck" in his ears, dipped under the water level in the tower and passed up through the hatch. Herbert stepped forward to close the hatch, but the rush of the expanding air was so great that in spite of himself he was forced up-



SUBMARINE "*K 15*" SECTION THROUGH CONNING TOWER.

wards through the opening and into the wheelhouse and then by pure good luck was carried by the escaping air aft and up through the hatch in the after end of the wheelhouse roof. He partly swam and was partly carried by the ascending air to the surface, and came up close to the diver's boat. Herbert's first words were "Where's Goodhart?" and we can imagine his horror when he was told that he had not appeared. Nor had the tin cylinder reached the surface, and long afterwards the brave commander, who truly gave his life for all of us, was found in the forward part of the wheelhouse. It is supposed that he was shot violently upwards by the rush of air and was stunned by contact with the wheelhouse roof. Herbert's arrival on the surface was a Godsend to us all, however, as he was able to give the rescue party definite details as to our condition and to advise as to the best means of assistance. The result of Herbert's efforts became evident to us at about 6 o'clock on Tuesday evening, when we were made aware by tapping on the hull that a H.P. connection had been made to our air system. He slightly opened one of the joints in the system and cautiously opened the inboard valve. To our disappointment we obtained not the air we so much needed, but salt water mixed with a few air bubbles, and at last we had to close the valve and try to tap out a message to say what was happening. Then followed another long wait while the diver disconnected and overhauled his air pipe, to find the cause of the trouble in a blank flange. This was put right; followed by more tapping; another cautious opening of the valve, and this time we were gladdened by a fine hissing rush of pure dry air. A little of this was allowed to escape into the hull and then the joint was made tight and

we proceeded to recharge our exhausted air bottles. This was about 4 a.m. on Wednesday morning, when we had been below for about 37 hours. About 5 a.m., as soon as we had charged up several groups of bottles to their full pressure of 2,500 pounds, we began to blow out all the forward tanks within our control. As we had no means of knowing when these were emptied we had to guess how long to keep the air on each, but as our supply was now ample we made reasonably sure that each was completely blown before passing to the next. Anxiously we watched the bubbles of our fore-and-aft spirit levels. We gave a shout of delight and watched the cheering indicator as it slowly moved to 5 degrees, 6 degrees, 7 degrees, 8 degrees, 9 degrees, 10 degrees, and that was as far as it was made to go; it could go no farther. But the vessel continued to rise forward, until at last those on the surface saw our bow rise out of the water and presently signalled to us that we were high enough and had better not blow any more, as the escaping air was endangering the diver. At this time the vessel lay with her stern some 12 feet deep in the mud and her stem head about 10 feet above water, the angle of longitudinal inclination being about 16 degrees.

Meantime, another connection was made to the hull. There was a 7-inch ventilator and hand-up which passed through both inner and outer hulls from the officers' quarters. The top cover was removed by the diver, a hole cut in it, and a 4-inch flexible armored hose securely attached. The cover was then replaced and most of the water sucked out of the pipe by means of a smaller suction hose. Word was then tapped to us to open the lower cover. This we did very cautiously and found that after a considerable quantity of water had come down air began to rush strongly out of our prison, showing that the pressure was still considerably above that of the atmosphere. The escaping air was so black and foul that our salvors marvelled that anyone could still be alive. We could now talk freely with those on the surface.

The diver had already found explanation of the disaster by discovering that the four air inlets to the boiler-room were fully open. These should, of course, have been closed before the signal "Engine Room Closed" was set in the control room, but by some oversight this had not been done. The accident was thus due to no defect in the design or construction of the vessel, but to a momentary forgetfulness on the part of someone who paid for his error with his life. When the vessel was ultimately examined, the lever controlling the air-inlet covers was found to be standing at "open."

The 4-inch tube, besides making communications as easy as they had previously been difficult, was large enough for the passage of small articles, and presently a small bottle of brandy was seen to be dangling on the end of a string. This was served round sparingly, the dish used being the brass cover of an electric switch. Next came milk and chocolate, liquid and solid. A high-pressure air pipe was passed down the 4-inch flexible hose and as its hissing end entered the hull we all gathered round it and whiffed it over our faces, breathing in lungsfuls of invigoration. Never had we so fully appreciated the value of fresh air. As the hull became filled with fresh air and the foul air was expelled through the friendly flexible, we all revived wonderfully and hope began to speak again in a timid manner, though no one voiced his hope, as it was felt that at any moment and in any of many forms disaster might come.

Meantime, the problem of getting us out was exercising the minds of those on the surface. It was decided to pump away the water lying between the main hull and the superstructure forward, to cut a hole in the forecastle deck and another directly below it in the main hull. We were told that the water could be removed in about 20 minutes and that the holes could then be cut by the oxy-acetylene flames in a few minutes more.

We were to gather forward and prepare the way from below. Finally, a space just aft of the tank bulkhead was chosen. We tore away all the wood lining at this place and then clustered in a bunch on top of the torpedo tubes, eagerly awaiting the cutting of the hole through which our safety lay. After some delay the water level responded to the efforts at the pumps and in a few minutes the inner hull lay bare to the rescue party. The oxy-acetylene flame was set to work and soon the anxious watchers below saw its point burst through the roof of their prison. A hole about 18 inches square was quickly cut, and amid resounding cheers from the men crowding the decks of the rescue vessels we began to appear one by one out of the depths and on to the deck of *K. 13*.

It was about 10 p.m. on Wednesday night—55 hours after our dive—the moon was full and amid a bunch of vessels of all kinds illuminated by cluster lamps and crowded with staring faces, rose the snout of *K. 13* set at an absurd angle with a black square hole on its surface from which the last survivor was being helped to freedom and life.—"Shipbuilding and Shipping Record."

THE ACCIDENT TO *K. 13*.

We have already published an abstract of the paper contributed by Mr. Percy A. Hillhouse, B.Sc., in which he described the remarkable way in which the 48 men who were imprisoned alive when the *K. 13* sank were rescued after being submerged for 55 hours. A record should, however, be made of the efforts made by a number of draughtsmen, ironworkers and carpenters in preparing a long tube through which it was hoped to be able to rescue the imprisoned men. Captain Herbert, who had escaped from the sunken submarine, suggested a rescue tube, and it was immediately decided to construct one 27 inches in diameter and 60 feet in length, with a box at the lower end so arranged that it could be fitted over the outer hull in way of the amidship torpedo hatch. It was to be fixed in place by divers, guyed to the hull, and the joint caulked watertight. The necessary instructions reached Fairfield just after stopping time on Tuesday evening, but hasty recalls were issued. The designs were quickly prepared, and all night the ironworkers and carpenters wrought at the tube, box and pipe, and the whole was completed within 17 hours from the beginning of the drawings. A discharge pipe was fitted to the lower end of the tube and carried up to the surface on the outside, and it was decided to close the tube at the top by means of a bolted plate and blow the water out of the tube through this pipe. The cover could then be removed and somebody lowered through the tube to get the people inside the hull to open the torpedo hatch, through which the imprisoned men could be hoisted to freedom. And, since it was not known whether those inside would be able to open the hatch, much less to lift it, it was decided, if necessary, to cut a hole in the cover by means of the oxy-acetylene blowpipe. Actually, the tube was never used, but it was a well-conceived idea, nobly executed, and it might have been of vital importance.—"Shipbuilding and Shipping Record."

THE FACTS ABOUT GERMAN SUBMARINE CONSTRUCTION.

No phase of the late war captured popular imagination to a greater extent than the German submarine campaign against shipping. In spite of the horror aroused in all civilized countries by the ruthless and utterly illegal conduct of that campaign, there was a widespread desire for information concerning the German underwater fleet. It need hardly be said

that the enemy himself did little to satisfy this curiosity. He drew what he fondly hoped was an impenetrable curtain over his U-boat preparations, and if the public on this side was largely ignorant as to the number and type of enemy submarines which had been built during the war, the German people themselves were equally in the dark. However, thanks to the amazing efficiency of our Naval Intelligence Division, the British Admiralty was kept well informed of what was happening on the other side of the North Sea, and therefore knew the number of German submarines built, being built, and projected at any given moment, together with their salient characteristics. Since the armistice a mass of information has been published on this subject, including fairly accurate details of special U-boat types, but hitherto no full and authentic list of the German submarine building effort during each year of the war has been placed before the public. We are now in a position to publish such tables, which we venture to think will prove of considerable interest to our readers. The following tabular details and notes have been compiled from evidence submitted by the German Admiralty to the "Untersuchungsausschuss"—the Commission for investigating war responsibility—at Berlin. The only references which cannot be guaranteed as accurate in every respect are those relating to machinery, speed, and radius, which have been prepared on the basis of material from reliable, but not official, sources.

At the outbreak of war Germany possessed only 28 completed submarines. That figure has often been challenged, but it was undoubtedly correct, and there was no foundation for the rumors that a large number of additional boats had been built in secret. The truth was that the German naval authorities still hesitated to spend large sums of money on an untried weapon, and Grand Admiral von Tirpitz, who at that time was virtually the dictator of German naval policy, had repeatedly expressed his scepticism as to the value of submarines. On the other hand, the majority of these 28 boats possessed excellent nautical qualities, with a large cruising endurance, and were generally more formidable than had been suspected. Under the command of such skillful and intrepid captains as Weddigen, von Hersing, Arnauld de la Perière, etc., they caused us heavy losses, and the long voyages they made led to an exaggerated idea of their dimensions. In fact, the submarine *U 21*, which went from Wilhelmshaven to the Dardanelles in the spring of 1915, and there sank the battleships *Majestic* and *Triumph*, displaced only 669 tons, and was thus smaller than our boats of the *E* class. The largest German submarine completed in 1914 was of 875 tons, and it was not until the third year of the war that the 1,000-ton mark was reached. The great majority of the German submarine fleet consisted of boats of quite moderate size, averaging 800 tons at most. There were, of course, special types, such as the very large submersible cruisers, built for work far out at sea, and the diminutive so-called *Flanders* boats, of very limited radius, designed to operate in the North Sea and Channel from the base at Bruges. None of the boats ready in 1914 mounted guns. These first appeared in 1915. That year was noteworthy also for the début of the submarine minelayer, several boats of that type having been built in six months. In 1916 came the first of the "mine cruisers," which carried, in addition to guns and tubes, a store of mines. The most remarkable boats of 1917 were the seven *Deutschlands*, originally built for carrying cargo. When the United States joined the Allies Germany converted these boats into fighting craft, the reconstruction work being performed in the Germania yard at Kiel. In 1917 also was launched the *U 139*, a very large boat of 1,930 tons, mounting a pair of 5.9-inch guns and carrying a complement of 83. She was the first representative of the *U-Boote-Hatzen* class, upon which, by order of the Kaiser, were bestowed names commemorating "submarine heroes."

No objection could be taken to the name of Weddigen—applied to *U 140*—for that officer had behaved with a chivalry and humanity only too rare on the German side, and he met a heroic death while attacking the British Battle Fleet. But scarcely credible as it may seem, it is none the less a fact that *U 139* was named after Schweiger, the officer who, when in command of the *U 20*, sank the *Lusitania*. During the final year of the war the output of submarines comprised a variety of types, and a month or two before the armistice a new and huge programme of submarine construction had been drawn up by Admiral Scheer, who succeeded Admiral von Capelle in September, 1918. No fewer than 437 submarines were being built or on order at the date of the armistice. Table No. 1 enumerates the German submarines which were complete on August 1, 1914, and those added before the end of that year. The gun armament of all these boats was first mounted in 1915.

A study of Table No. 1 will show that Germany was experimenting with many different designs, and had not then adopted a standard type, such for example, as we had chosen in the *E* class. The *U 1* was comparable in size, speed, and armament with our *B* boats, of which she was a contemporary, while the *U 2* was slightly larger than our *C's*. The first really efficient German boats were the *U 5-8*, which, though slightly smaller than our *D* class, were of larger radius and better armed, the speeds being about equal. In the next series, *U 9-12*, there was a slight fall in displacement. The nearest approach to uniformity of design is found in the ten boats *U 19-28*. These boats were capable of traveling at least 3,000 miles without replenishing their oil tanks, and considering the moderate size, their habitability appears to have been good. The only novel type introduced in 1914 was the *U A*, a boat designed to operate in coastal waters. Later on the features of this design were developed in the *U B* type, of which a very large number was built. At the end of 1914 thirty-one boats had been built, but in the interval five had been lost, leaving twenty-six still available. This, then, was the force with which Germany, according to her proclamation of February, 1915, proposed to "blockade" Great Britain! By that time, however, she had begun to realize the possibilities of submarine warfare, and the shipbuilding and engineering industry of the German Empire was organized with a view to accelerating the production of U-boats. But, strangely enough, the principle of standardization was not accepted, and, although groups of as many as fifteen and seventeen boats were built to uniform design, seven distinct types were represented among the sixty-two boats constructed in 1915. Their details were as given in Table II.

With the exception of the Special *U B* and *U C* coastal types, all the boats included in Table No. II were ocean-going boats, which had a radius of action of from 3,500 to 4,000 miles. The increasing power of the gun armament is a noticeable feature of this phase, another being the appearance of small mine-laying submarines. During 1916 the total output of boats reached ninety-five, but two-thirds of that number were small coastal submarines and mine-layers. Particulars of them are given in Table III.

The largest units built in 1916 were the *U 93-95*, of 859 tons. Their best surface speed was 17 knots. It is of interest to note that in the spring of that year the British Navy included submarines (*J* class) of 1,820 tons displacement, which attained a speed of over 19 knots. The ten German boats *U 71-80* were of a somewhat novel type, embodying as they did remarkable powers of offense in moderate dimensions. They were armed with two torpedo tubes and a 3.4-inch gun, and carried also 18 mines. A modified edition of this type was produced in the *U C* class of 1916, numbering 31 boats, which mounted three tubes and one 3.4-inch gun and carried 18 mines.

TABLE I.—*The German Submarine Establishment on August 1st, 1914.*

Numerals.	No. of units.	Displacement, tons.	Aggregate displacement, tons.	Armament. Guns.	Tubes.	Torpedoes.	Mines.	Complement.
U. 1	1	238	238	—	1	2 18in.	—	22
U. 2	1	341	341	—	4	6 18in.	—	22
U. 3–4	2	421	842	1 4-pdr.	4	6 18in.	—	22
U. 5–8	4	505	2,020	—	4	8 18in.	—	28
U. 9–12	4	493	1,972	1 4-pdr.	4	6 18in.	—	26
U. 13–15	3	516	1,548	—	4	6 18in.	—	29
U. 16	1	489	489	1 4-pdr.	4	6 18in.	—	29
U. 17–18	2	564	1,128	1 4-pdr.	4	6 18in.	—	29
U. 19–22	4	650	2,600	2 3.4in.	4	6 19.7in.	—	35
U. 23–26	4	669	2,676	2 3.4in.	4	6 19.7in.	—	35
U. 27–28	2	675	1,350	1 4.1in.	4	6 19.7in.	—	35
Boats Added in 1914.								
U.A.	1	268	268	1 4-pdr.	3	5 18in.	—	21
U. 29–30	2	675	1,350	1 4.1in.	4	6 19.7in.	—	35
No of boats at end of 1914	31		16,822					

TABLE II.—*Submarine Construction in 1915.*

Numerals.	No. of units.	Displacement, tons.	Aggregate displacement, tons.	Armament. Guns.	Tubes.	Torpedoes.	Mines.	Complement.
U. 31–41	11	685	7,535	1 4.1in.	4	6 19.7in.	—	35
U. 43–50	8	725	5,800	1 4.1in.	6	6 19.7in.	—	36
U. 51–53	3	715	2,145	1 4.1in. 1 3.4in.	4	8 19.7in.	—	35
U. 57–59	3	768	2,304	1 4.1in. 1 3.4in.	4	8 19.7in.	—	35
U. 66–70	5	791	3,955	1 4.1in.	5	10 18in.	—	36
UB. 1–17	17	127	2,159	—	2	2 18in.	—	14
UC. 1–15	15	168	2,520	—	—	—	12	14
No. of boats built in 1915	62		26,418					

TABLE III.—*Submarine Construction in 1916.*

Numerals.	No. of units.	Displacement, tons.	Aggregate displacement, tons.	Armament. Guns.	Tubes.	Torpedoes.	Mines.	Complement.
U. 54–56	3	715	2,145	1 4.1in. 1 3.4in.	4	8 19.7in.	—	35
U. 60–62	3	768	2,304	1 4.1in. 1 3.4in.	4	8 19.7in.	—	35
U. 63–65	3	810	2,430	1 4.1in.	4	8 19.7in.	—	35
U. 71–80	10	758	7,580	1 3.4in.	2	2 19.7in.	36	32
U. 81–86	6	808	4,848	1 4.1in. 1 3.4in.	4	8 19.7in.	—	35
U. 87–89	3	757	2,271	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 93–95	3	859	2,577	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36

U. 71–80	10	755	7,550	1 3.4in.	2	2 19.7in.	36	32
U. 81–86	6	808	4,848	1 4.1in. 1 3.4in.	4	8 19.7in.	—	35
U. 87–89	3	757	2,271	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 92–95	3	859	2,577	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 99–101	3	750	2,250	1 4.1in. 1 3.4in.	4	12 19.7in.	—	35
UB. 18–29	12	263	3,156	1 3.4in.	2	4 19.7in.	—	23
UB. 30–47	18	274	4,932	1 3.4in.	2	4 19.7in.	—	23
UC. 16–46	31	417	12,927	1 3.4in.	3	4 19.7in.	16	26
No of boats built in 1916	95		47,390					

TABLE IV.—*Submarine Construction in 1917.*

Numerals.	No. of units.	Displacement, tons.	Aggregate displacement, tons.	Armament.				Complement.
				Guns.	Tubes.	Torpedoes.	Mines.	
U. 90–92	3	757	2,271	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 93–98	3	859	2,577	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 102–104 ..	3	750	2,250	1 4.1in. 1 3.4in.	4	12 19.7in.	—	35
U. 105–109 ..	5	830	4,150	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 117–118 ..	2	1164	2,328	1 5.9in.	4	24 19.7in.	42	40
U. 123–123 ..	2	1164	2,328	1 5.9in.	4	24 19.7in.	42	40
U. 138	1	1175	1,175	1 5.9in.	6	14 19.7in.	—	46
U. 139	1	1930	1,930	2 5.9in.	6	19 19.7in.	—	53
U. 151–157 ..	7	1510	10,570	2 5.9in.	3	18 19.7in.	—	76
UB. 48–90	43	516	22,188	1 4.1in.	5	10 19.7in.	—	24
UC. 47–79	33	417	13,761	1 3.4in.	3	4 19.7in.	16	26
No. of boats built in 1917	103		65,528					

TABLE V.—*Submarine Construction in 1918.*

Numerals.	No. of units.	Displacement, tons.	Aggregate displacement, tons.	Armament.				Complement.
				Guns.	Tubes.	Torpedoes.	Mines.	
U. 110–114 ..	5	830	4,150	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 119–120 ..	2	1164	2,328	1 5.9in.	4	24 19.7in.	42	40
U. 124–126 ..	3	1164	3,492	1 5.9in.	4	24 19.7in.	42	40
U. 136	1	1175	1,175	1 5.9in.	6	14 19.7in.	—	46
U. 140–141 ..	2	1930	3,860	2 5.9in.	6	19 19.7in.	—	53
U. 142	1	2158	2,158	2 5.9in.	6	19 19.7in.	—	53
U. 160–164 ..	5	821	4,105	2 4.1in.	6	12 19.7in.	—	36
UB. 91–132 ..	42	516	21,672	1 4.1in.	5	10 19.7in.	—	24
UB. 142–143 ..	2	523	1,046	1 4.1in.	5	10 19.7in.	—	24
UB. 148–149 ..	2	523	1,046	1 4.1in.	5	10 19.7in.	—	24
UC. 80–105	16	491	7,856	1 4.1in.	3	7 19.7in.	14	32
No. of boats built								

Numerals.	No. of units.	Displacement, tons.	Aggregate displacement, tons.	Armament. Guns.	Tubes.	Torpedoes.	Mines.	Complement.
U. 1	1	238	238	—	1	5 18in.	—	22
U. 2	1	341	341	—	4	6 18in.	—	22
U. 3–4	2	421	842	1 4-pdr.	4	6 18in.	—	22
U. 5–8	4	505	2,020	—	4	6 18in.	—	28
U. 9–12	4	493	1,972	1 4-pdr.	4	6 18in.	—	28
U. 13–15	3	516	1,548	—	4	6 18in.	—	29
U. 16	1	489	489	1 4-pdr.	4	6 18in.	—	29
U. 17–18	2	564	1,128	1 4-pdr.	4	6 18in.	—	29
U. 19–22	4	650	2,600	2 3.4in.	4	6 19.7in.	—	35
U. 23–26	4	669	2,676	2 3.4in.	4	6 19.7in.	—	35
U. 27–28	2	675	1,350	1 4.1in.	4	6 19.7in.	—	35
Boats Added in 1914.								
U.A.	1	368	368	1 4-pdr.	3	5 18in.	—	21
U. 29–30	2	675	1,350	1 4.1in.	4	6 19.7in.	—	35
No of boats at end of 1914	31		16,822					

TABLE II.—*Submarine Construction in 1915.*

Numerals.	No. of units.	Displacement, tons.	Aggregate displacement, tons.	Armament. Guns.	Tubes.	Torpedoes.	Mines.	Complement.
U. 31–41	11	695	7,535	1 4.1in.	4	6 19.7in.	—	35
U. 43–50	8	725	5,800	1 4.1in.	6	6 19.7in.	—	36
U. 51–53	3	715	2,145	1 4.1in.	4	6 19.7in.	—	35
U. 57–59	3	768	2,304	1 3.4in. 1 4.1in. 1 3.4in.	4	8 19.7in.	—	35
U. 66–70	5	791	3,955	1 4.1in.	5	10 18in.	—	36
UB. 1–17	17	127	2,159	—	2	2 18in.	—	14
UC. 1–15	15	168	2,520	—	—	—	12	14
No. of boats built in 1915	62		26,418					

TABLE III.—*Submarine Construction in 1916.*

Numerals.	No. of units.	Displacement, tons.	Aggregate displacement, tons.	Armament. Guns.	Tubes.	Torpedoes.	Mines.	Complement.
U. 54–56	3	715	2,145	1 4.1in. 1 3.4in.	4	8 19.7in.	—	35
U. 60–62	3	768	2,304	1 4.1in. 1 3.4in.	4	8 19.7in.	—	35
U. 63–65	3	810	2,430	1 4.1in.	4	8 19.7in.	—	35
U. 71–80	10	755	7,550	1 3.4in.	2	2 19.7in.	38	32
U. 81–86	6	808	4,848	1 4.1in. 1 3.4in.	4	8 19.7in.	—	35
U. 87–89	3	757	2,271	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 93–95	3	859	2,577	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 96–101	3	750	2,250	1 4.1in. 1 3.4in.	4	12 19.7in.	—	35
UB. 18–29	12	263	3,156	1 3.4in.	2	4 19.7in.	—	23
UB. 30–47	18	274	4,932	1 3.4in.	2	4 19.7in.	—	23
UC. 16–46	31	417	12,927	1 3.4in.	3	4 19.7in.	18	20

U. 93–95	3	859	2,577	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 96–101	3	750	2,250	1 4.1in. 1 3.4in.	4	12 19.7in.	—	35
UB. 18–29	12	263	3,156	1 3.4in.	2	4 19.7in.	—	23
UB. 30–47	18	274	4,932	1 3.4in.	2	4 19.7in.	—	23
UC. 18–48	31	417	12,927	1 3.4in.	3	4 19.7in.	16	26
No of boats built in 1916	95		47,390					

TABLE IV.—*Submarine Construction in 1917.*

Numerals.	No. of units.	Displacement, tons.	Aggregate displacement, tons.	Armament.				Complement.
				Guns.	Tubes.	Torpedoes.	Mines.	
U. 90–92	3	757	2,271	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 93–98	3	859	2,577	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 102–104 ..	3	750	2,250	1 4.1in. 1 3.4in.	4	12 19.7in.	—	35
U. 105–109 ..	5	830	4,150	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 117–118 ..	2	1164	2,328	1 5.9in.	4	24 19.7in.	42	40
U. 122–123 ..	2	1164	2,328	1 5.9in.	4	24 19.7in.	42	40
U. 125	1	1175	1,175	1 5.9in.	6	14 19.7in.	—	46
U. 139	1	1930	1,930	2 5.9in.	6	19 19.7in.	—	53
U. 151–157 ..	7	1510	10,570	2 5.9in.	2	18 19.7in.	—	76
UB. 48–90	43	516	22,188	1 4.1in.	5	10 19.7in.	—	34
UC. 47–79	33	417	13,761	1 3.4in.	3	4 19.7in.	18	26
No. of boats built in 1917	103		65,528					

TABLE V.—*Submarine Construction in 1918.*

Numerals.	No. of units.	Displacement, tons.	Aggregate displacement, tons.	Armament.				Complement.
				Guns.	Tubes.	Torpedoes.	Mines.	
U. 110–114 ..	5	830	4,150	1 4.1in. 1 3.4in.	6	12 19.7in.	—	36
U. 118–120 ..	2	1164	2,328	1 5.9in.	4	24 19.7in.	42	40
U. 124–126 ..	3	1164	3,492	1 5.9in.	4	24 19.7in.	42	40
U. 136	1	1175	1,175	1 5.9in.	6	14 19.7in.	—	46
U. 140–141 ..	2	1930	3,860	2 5.9in.	6	19 19.7in.	—	53
U. 142	1	2158	2,158	2 5.9in.	6	19 19.7in.	—	53
U. 160–164 ..	5	821	4,105	2 4.1in.	6	12 19.7in.	—	36
UB. 91–122 ..	42	516	21,672	1 4.1in.	5	10 19.7in.	—	34
UB. 142–143 ..	2	522	1,044	1 4.1in.	5	10 19.7in.	—	34
UB. 148–149 ..	2	522	1,044	1 4.1in.	5	10 19.7in.	—	34
UC. 80–105	16	491	7,856	1 4.1in.	3	7 19.7in.	14	32
No. of boats built in 1918	81		52,868					

We come now to 1917, which brought the first German *Untersee-Kreuser* on the scene. In the previous year the submarine freighters of the *Deutschland* class had been turned out to circumvent the British blockade. The nameship made two successful voyages across the Atlantic, and seven more boats were built of the same design. One of them, named the *Bremen*, left Germany in the autumn of 1916 for an American port, but never arrived. Not until after the armistice was it made known that the vessel had been lost with all hands in attempting to make a "crash dive" necessitated by the approach of a British patrol. Before the remaining boats of the *Deutschland* class were ready America had declared war, and their occupation was gone. They were at once altered into combatant vessels, two torpedo tubes being built into the bows and a pair of 5.9-inch guns mounted before and abaft the conning-tower. As we write the *Deutschland* herself lies moored off the Temple Pier for public inspection, the proceeds going to a worthy charitable fund. She is by no means an object of beauty, but her squat appearance and generous lines are suggestive of seaworthiness. These vessels are often spoken of as the first German "submersible cruisers," but that distinction belongs to the *U 117* and *118*. They were nearly 400 tons lighter than the *Deutschlands*, and mounted only one 5.9-inch gun, but they had four tubes and were fitted to carry mines. A very much larger boat, also built in 1917, was the *U 139* (Schweiger), of 1,930 tons. The total deliveries in 1917 are set forth in Table No. IV.

Towards the end of the third year of war Germany, therefore, was completing submarines at the rate of about two per week. She was also devoting more attention to the building of very large boats, which could operate thousands of miles away from the home base. This departure was a tribute to the growing efficacy of our anti-submarine patrols in the Narrow Seas. When the United States became a belligerent the Germans decided to lay minefields in the coastal waters of their new enemy, and the big submersible minelayers *U 117-118* and *U 122-123* were built especially for that purpose. They achieved a certain amount of success as minelayers, but as commerce destroyers they were a complete failure, proving less dangerous than the smaller U-boat, which could dive and manœuver more rapidly. It is probable, too, that the adoption of the convoy system in 1917 was mainly responsible for the defeat of these large submarine corsairs, which, despite their size and formidable armament, were quite as vulnerable to attack by gunfire, the ram, and the depth charge as the smallest of their species. The Germans appear to have realized this, for their programme of 1918 included only nine U-cruisers, the remaining 72 boats being of comparatively small dimensions. The output in this, the last year of the war, was as shown in Table No. V.

An analysis of the foregoing tables gives the following comprehensive survey of German submarine building activity during the war—see Table VI.

TABLE VI.

	Number	*Aggregate displacement.*
Boats completed in 1914	31	16,822
Boats added in 1915	62	26,418
Boats added in 1916	95	47,390
Boats added in 1917	103	65,528
Boats added in 1918	81	52,888
Totals	372	209,046

These 372 boats mounted between them 491 guns, viz., thirty-three 5.9-inch, one hundred and ninety-two 4.1-inch, one hundred and sixty-six 3.4-inch, and ten 5 centimeter, or 4-pounders, together with 1,492 torpedo tubes. They carried 2,314 mines, and their complements numbered 11,073 officers and men. In Table No. VII the number of submarines possessed by Germany—allowing for losses—at the end of each war year is shown:—

TABLE VII.

	Boats built.	*Losses.*	*Establishment on*	
End of 1914.....	31	5	Jan. 1, 1915.....	26
End of 1915.....	93	25	Jan. 1, 1916.....	68
End of 1916.....	188	50	Jan. 1, 1917.....	138
End of 1917.....	291	122	Jan. 1, 1918.....	169
End of 1918..... (Nov.)	372	202	Nov. 11, 1918.....	170

In view of these figures, the British Admiralty was clearly justified in declaring that the submarine menace was "checked" or "held" towards the close of 1917. After that date we were sinking the U boats rather more quickly than they could be built, and the steady improvement in our counter-offensive was displayed by the sudden increase of U-boat casualties in 1918.—"The Engineer."

SHIPS THAT WE SHOULD BUILD.

Although the *Scientific American* has urged strongly that it would be folly to go ahead just now with the construction of the six 42,000-ton battleships, we would not have the impression go forth that we are opposed to all naval ship building. On the contrary, there are certain types of vessel of which the Navy stands sorely in need, vessels without which it would still be characterized by that lack of balance which was so glaringly manifest, and to which we so often drew attention, in the years preceding the war.

As matters stand today, we have no scout cruisers that are worthy of the name. The *Chester*, *Salem*, and *Birmingham*, which did good work during the war in convoying, are too small and too slow to meet the exacting requirements of modern scouting service. The scouts of the British Navy have gone up in size to from 5,000 to about 10,000 tons; they carry heavy armaments of 6-inch and 7.5-inch guns, and they have speeds of about 30 knots. High speed is an absolute necessity in ships that must scout far ahead of a fleet, say, of battle-cruisers whose speed may range from 28 to 32 knots and who maintain high speed in any weather that comes their way. For this reason the scout must have length and weight.

Now we had made an excellent start before we entered the war by authorizing ten large and powerful scouts of 35 knots' speed, work upon which is now being prosecuted; but ten of these ships is not sufficient for a navy of our size, and an additional ten should receive the endorsement of Congress. Just what the present design of these scouts is has not been made known. The original design was not altogether satisfactory, there being some question of longitudinal weakness in the hulls; but we presume that has been set right and that we now have a standard design to which we can build in numbers.

Another type of greatly-needed vessel in our Navy is what is called the flotilla leader. This is simply an unusually large destroyer of about 2,000 tons' displacement. It is a development of the war, and on each side in the various engagements these vessels acted as the leaders and flagships of the

separate flotillas of destroyers when going into action. Their greater size enables them to carry all the essential facilities aboard for a small flagship, with accommodations of a flotilla commander. Compared with the destroyer, they have superior signalling and range-finding appliances, their battery is heavier, and they have a radio equipment of much greater range. Furthermore, when battle-cruisers are using their full speed in an engagement, the average destroyer is rather put to it in the effort to match the battle-cruiser's speed, and hence flotilla leaders, with their greater size, are selected to act as battle-cruiser screens on such occasions.

Finally, we should build a number of submarines of a more or less experimental type. The board recommends, first, a submarine with a very wide radius of action, a heavy armament and the longest practical radio-sending range. Speed both on the surface and below would be sacrificed to other qualities, and the vessel would carry four bow and two stern tubes, fifteen 21-inch torpedoes, two 6-inch guns and an anti-aircraft gun. The length would be 300 feet and the surface displacement 2,000 tons. It is also proposed to build a long-radius mine layer, similar to the *U-117*; and, thirdly, we should build a "general purpose submarine" of about 900 tons, which should be the best combination that the department can evolve as the result of past experiences gained with different designs of our own and German U-boats.—"Scientific American."

REVIEW OF THE YEAR 1919.

NAVAL.

The opening of the present year found the United States Navy in an exceedingly strong position relatively to the other navies of the world. A comparison of dreadnought strength showed that, if the present building programs of the various powers are completed, the United States will be stronger than the combined forces of the next three great naval powers. We shall possess 19 dreadnoughts as against 21 for Japan, France and Italy combined. Great Britain, of course, because of her superb shipbuilding effort in the great war, was stronger than ourselves; but in agreement with the suggestions of our President, all of the great naval powers, except possibly Japan, have ceased capital ship construction and are merely completing some of the lesser units which were partially completed during the war. Great Britain has got rid of all her pre-dreadnoughts and armored cruisers, some of her earlier battle-cruisers, and is seriously contemplating the striking of her early 12-inch gun dreadnoughts from the list. The United States, the protagonist of disarmament at the Peace Conference, is the only navy that is increasing its naval forces, and this she is doing to the extent of building 16 battleships and battle-cruisers. The Naval Board has recommended an additional three capital ships, making 21 in all. The trials of the dreadnought *New Mexico*, our first battleship to be driven by the new electric drive, were a great success. In addition to the admitted advantage of easy controllability, the ship has already shown herself to be superior in economy to our battleships using the reciprocating engine and steam turbine drive. This makes it fairly certain that the electric drive will be the drive of the future for all of our vessels. The British seem well satisfied with their mechanical reduction gear which is being utilized for the transmission of over 37,000 horsepower on a single shaft. Our new 42,000-ton battleships, known as numbers 49 to 54, with 684 feet overall length, have the enormous beam of 106 feet; they will carry twelve 16-inch and sixteen 6-inch guns and have a speed of 23 knots. Our old friends, the battle-cruisers, have been greatly modified. By increasing the beam to 105½ feet, it has been possible to get all

the electric and steam machinery below the protective deck without reducing the anti-torpedo protection. Displacement has gone up from 35,000 to 43,500 tons, speed has been dropped from 35 to 33.25 knots, and, we have no doubt that the armor plan has been greatly increased. These changes put our battle-cruisers in the same class as the *Hood*. They will be, practically, battleships with battle-cruiser speed, and will carry eight 16-inch and sixteen 6-inch guns. Speeds have increased in every type of ship. The latest British destroyers have been showing from 37 to approximately 40 knots, this last being achieved by the *Turquoise*, which steamed for four hours at an average speed of 39.6 knots.

The last few months of the year have brought forth some startling statements from high naval authorities as to the future of naval warfare and the composition of naval fleets. Lord Fisher and Admiral Scott believe that the day of the battleship has gone and that the command of the air will mean the command of the sea. May be; but it has yet to be proved. At the same time, it is significant that Great Britain should be directing her energies and her wealth so lavishly toward war in the air. She is building sea-planes of vast size and capacity and although her original airplane program has been modified, it is still very ambitious. The revulsion against the submarine due to German misuse of it has largely subsided, and there is a consensus of opinion among naval men that this type will figure even more extensively in the future shipbuilding programs of the various navies. The type of ship most favored seems to be one of our *S* type, of about 850 tons' displacement. Whether huge submarines of the British *K* type of 2,000 to 3,000 tons' displacement and 24 knots' speed will be permanently adopted is a question for the future. They were built as fleet submarines, intended to cruise with the fleet and engage in fleet action. There is the question of the future of high-speed, torpedo-carrying motor boats. The British coastal motor boats, carrying one or two torpedoes on deck, and having a speed of 40 knots, seem to have acquitted themselves so well as to have become popular for work against both destroyers and submarines. On this side of the water we have seen a meritorious attempt along the same lines in the one-man torpedo boat, which, because of its low cost and comparative invisibility, lends itself admirably to harbor and coast defense.—Extract from "Scientific American."

THE HUMAN ELEMENT IN ENGINEERING.*

The general impression conveyed to my mind by a perusal of past presidential addresses, is that the material side of engineering has been exploited rather more than the personal or human element, and I propose to take advantage of my position here this evening to help to redress the balance.

For many years to come the world will want all the engineers it can produce to repair the ravages of war, for rebuilding, for reconstruction and for the opening up of new countries and new trade routes. We can afford to neglect for the present the competition of aliens; there is work for all. It is, or it should be, the proud boast of the engineer that his particular work, rightly applied, is the greatest civilizing agency that exists.

Railways, ships, motor cars, aircraft, bridges, tunnels, roads, docks, improved telegraphs and telephones, mechanical appliances in agriculture and

*Abstract of presidential address read before the Liverpool Engineering Society by Mr. J. Hamilton Gibson, November 5, 1919.

mining, irrigation, lighting and power schemes, the storage, preservation and transport of foodstuffs, good dwellings, sanitation, water supply—what vast fields of endeavor and enterprise for the vigorous youth with a spark of imagination! With education and training such as is provided for engineers in these days the well-equipped young man has the world at his feet in whichever direction he elects to turn.

But he must remember that all successful men—including engineers—are specialists, and however complete his general training may be, he must decide that he will be master of one thing, and, if possible, a paramount authority on that subject.

I do feel very strongly that engineers, as a class, are too inarticulate. They prefer that their achievements should speak for them. There they make a big mistake. How often have we seen the credit for a clever piece of work filched from the man who was really responsible, just because he was too retiring or too altruistic to keep himself in evidence. I am not suggesting for one moment that a brother engineer would willingly or wittingly rob another of the work of his hand and brain. Engineers, as a rule, are quick to recognize a meritorious performance. But in all large and complicated enterprises there are always others—those whose work is administrative, or clerical, or merely ornamental. These persons are apt to get into the limelight and take all the "kudos", not consciously, maybe, but simply and solely because they happen to be the only men in sight. Marine engineers suffer a considerable measure of eclipse of this sort. Their best efforts, often masterpieces of ingenuity and design, are entombed in a kind of steel coffin, and never again see the light of day. And they themselves are out of sight also, and therefore out of mind. It took a *Titanic* disaster to impress upon a heedless world the quiet heroism and devotion to duty that can exist down below among men who calmly control the volcanic energies of 100,000 horsepower.

There, if the young engineer is a draughtsman worthy of the name, he is daily and hourly, if not exactly inventing, at any rate working out improvements. It is the normal procedure in every well-regulated drawing office. No sooner is a new design completed—I refer now particularly to a plan of engines or turbines, or a general arrangement of machinery—than it immediately becomes obsolete. There is no finality in good engineering practice. However perfect a design may appear to be, the complete draughtsman can always go one better when he clears his board and starts afresh.

Frequently he never sees the actual work in the shops or on the ship, and so long as everything fits together and works all right, nothing more is heard of it. This is not as it should be. A little consideration, a word of commendation, to the man whose careful, conscientious thought and skill in the early stages of an important job have made it a triumphant success, is not only his due, but would go a long way to remove that feeling of injustice and dull resentment that was so pronounced in recent correspondence in the engineering papers. The fact is that the drawing office is, and should be, recognized as the brain-center of the whole organization. Any carelessness, the slightest mistake or miscalculation, may cause endless trouble and expense.

The time-honored custom whereby engineering draughtsmen must have worked in the shops and become accustomed to the feel and touch of the materials of construction and the handling of tools is an eminently wise provision; and no doubt accounts for the marvellously few "bloomers" that occur.

It is a commonplace that millions of pounds' worth of material is ordered and manipulated through the drawing office. Every plate, forging, casting, or detail goes into place and must be equal to the task it has to

perform. If an engine, it must work sweetly and effectively forever and a day. Now, in the rush of ordering material in the early stages of a job to maintain delivery dates according to contract, there is abundant opportunity for errors to creep in. But I think it will be generally admitted that the percentage of stuff that goes wrong or that has to be scrapped is infinitesimal; and this is only rendered possible by the particular and peculiar training of the engineering draughtsman to which I have referred. He is mentally building the engine, or boiler, or girder—as he draws the parts; and that makes all the difference between a practicable working drawing and one that is not.

Several firms in recent years have adopted a surprisingly enlightened policy. A system has been inaugurated whereby any such improvement produced by an employee meets with an immediate monetary reward as soon as its value is established. A patent is taken out in the joint names of the firm and the inventor, the firm paying all expenses, and allotting to the inventor a generous proportion of any royalties that may accrue. This is a pleasant contrast to the days not so long ago, when an employee who presumed to invent anything and patent it at his own expense was looked upon with disfavor, and under suspicion of disloyalty. If the invention was good it was cheerfully appropriated by any unscrupulous manufacturer, who knew full well that the inventor could not afford to enter proceedings against him.

Generally, everybody, the whole community, gains by a well-protected and intelligently-developed invention. Unfortunately, the original inventor is sometimes victimized; but it is often his own fault. It is really comic to watch the antics of some amateur inventors. They ask for an interview, and then they are scared to death for fear you should tap their idea before you have committed yourself or your firm to buy a "pig in a poke." Often they have not dared to consult a patent agent. Not they! What is to prevent him twisting the thing round until they cannot recognize it, and then showing them that it has been done before? And as for the Government—why should they let the Government peddle the work of their brains at 6d. a time? It is all very wrong-headed, of course. You can make no progress with a man who distrusts you, and doubtless in some hard cases in the past there has been justification for his attitude.

The joint patent system, however, is a powerful protection for the employee, and of advantage to all parties concerned. From what I have seen the system works well and has immense possibilities in cheapening and facilitating workshop methods.

One of the saddest things in life is to see a man, well past his prime, having worked faithfully and conscientiously all his days, looking forward with fearful apprehension to the time when he shall receive the polite intimation, "Your services are no longer required." Their one wish is to die in harness, so as not to become a burden at home. Too often, alas, their dismissal is tantamount to a sentence of death, and they do not survive long to be a burden to anybody.

Why all this bitterness and tribulation? Just because they had not the foresight when young to weigh themselves up and say, "Well, it is evident that I am never going to be anything more than a servant. I must see to it, before it is too late, that the firm or corporation I work for has an adequate pension scheme, and that my declining days shall not be clouded by the specter of want."

A young man, over twenty years ago, in the plenitude of his powers, decided to make the change. He was talented and brilliant, he had promise of quick promotion; but was content to suffer a considerable diminution in salary for the prospect of a sure pension and provision for his dependents. Several of his colleagues, who thought he was mad, have since gone

under. He himself is looking forward with pleasurable anticipation to an early retirement, when he will be free to pursue the hobbies that have always engrossed his leisure hours.

There is no valid reason why any old employee should view the future with misgiving; on the other hand, it is only fair that the veterans, who have done their turn in the world's work, and have borne the burden and heat of their day, should not block the advance of the younger men. Autumn leaves must fall to make way for the spring foliage. Surely it should not surpass the wit of man for a federation of employers and insurance companies to evolve a scheme whereby these veterans would be saved from the anxiety and humiliation of hanging on to the means of a livelihood when they are getting past work. It would appear to be a comparatively simple thing to extend the Workmen's Insurance Act to include the higher grades and staff men. Something of the kind is in operation in the Foremen's Mutual Benefit Society. The cost and risk could be assessed from existing actuarial tables. The beneficiaries would be willing to contribute a fair share. Certificates should carry over from one firm to another as necessitated by the fluctuation of work, and in this connection the Government could, if it would, exercise a wise control which would make it a truly national institution. The ultimate result would be that a pension commensurate with the position to which the man had attained on retirement would follow naturally and automatically as a matter of course, without any suggestion of favor, or grace, or consideration of special merit; and no one, whatever his circumstances, or however well-to-do, need be ashamed to accept it. Happily, there are signs of awakening. It is a hopeful sign when one finds the chairman of great business combinations employing tens of thousands of hands—going out of his way to preach and practice the new doctrine.

Why engineers should excel in altruism is a puzzle. It is a by-product of their profession. The engineer seems to be continually working himself out of a job for the good of others. He constructs a machine that does the work of 10,000 men, and makes it so perfect and fool-proof that it can be manipulated by a child. There is nothing left for him on that machine; he may go away anywhere, so long as it is out of sight—and invent another and a better one if he can. There was a time when it was considered necessary to have two chief engineers on a vessel fitted with a double trunk engine, one to look after each cylinder. Nowadays one chief has the responsibility of any number of cylinders driving three or four shafts. What a grand thing it would be if the starting handles could be geared up to the bridge and the engineer eliminated altogether! Does he complain? Not a bit! He would be the first to create such a mechanism, and make his owners a present of the idea, if it were possible—which it may be some day.

The "ca' canny" slogan has not yet been adopted by the engineer. I do not mean the fitter, or the mere engine driver; but the real complete engineer, whose instinct it is to create, to invent, to design and construct. He can no more help doing it than can a doctor who is ready at any hour of the day or night to answer the call of duty; or the artist, or the poet, who must express himself on canvas or in verse whether it pays or not. In fact, the engineer in charge of a great installation of machinery is in very much the same position as the house surgeon in some big institution. His job is not so much to work eight hours a day manufacturing things; but to be always at his post, watching, thinking, measuring, recording, taking pressures and temperatures, sampling fuels, ash, oil, water—and ready for any and every emergency. When a joint blows out in the dead of night he doesn't expect to be paid at overtime rates because it isn't his watch. It will be calamitous if ever engineers become infected with that peculiar brand of trades unionism which involves paralysis and inaction in

emergencies. Let them bargain as they will for better terms, wages, salary, or remuneration, but remember that this will not alter the character of their work, the conditions are fixed by the immutable laws of Nature. Assuming that they play their cards well, they may perhaps in time become as well off as the police force—good pay, sickness benefits and superannuation before they are worn out. If that can be "engineered" during this period of reconstruction it will be a great point gained.

The material side of engineering is fairly well provided for. One has no feeling of trepidation that the goods will not be delivered, or that they will not stand the stress and wear of active service.

Is it too much to expect that the personnel, the hand and brain workers in engineering, shall receive equal consideration with the materiel, the instruments and products of their labors? This great question is receiving anxious thought in influential quarters, and some tangible result is confidently looked for. Let shareholders once realize that they will not suffer financial loss, but will actually be the gainers, and the welcome change cannot be long delayed. All of us who have regard for law and order and constitutional measures hope that the change will come about as harmoniously, and peacefully, as it will surely and inevitably. If any propagandist movement is necessary it is hoped that engineers will follow the lead of the medical and legal professions rather than that of the trades unions. It would be much more dignified and stately, and probably more effective.—"Engineering."

PROPELLER SHAFTING.

The propeller shaft is one of the most important of the details of the equipment of a vessel, no matter what type of propelling machinery is installed, and yet while the theory underlying the strength of such shafts to resist torsion, thrust and bending, can be considered as being thoroughly understood, agreement has not yet been reached as to the margin of safety which must be provided to allow for such effects as vibration, racing of propeller, errors of alignment either in erection or subsequently, etc., and this is one of the subjects which is now being investigated by the British Marine Engineers' Design and Construction Committee. That some such investigation is necessary is shown by the fact that the Board of Trade and the different classification societies have rules which give results which differ considerably for shafts to work under the same conditions. Thus for propelling machinery developing a maximum of 4,000 horsepower at 100 revolutions per minute, the following figures are obtained:—

	Board of Trade.	*Lloyd's.*	*British Corporation.*
Diameter of shaft, in inches	13.41	14.09	13.75
Stress in pounds per square inch	5,330	4,519	4,944

It is apparent, therefore, that even in so fundamental a question as that of diameter of shaft considerable differences of opinion exist among experts. When we come to the details of propeller shaft design such as length and pitch of bearings, shaft couplings, stern tubes, etc., the difference of opinion is even more pronounced, and there is ample scope for authoritative research into the above and many other problems in connection with the equipment between the main engines or gearing and the propeller.

In a very interesting paper entitled "Marine Propelling Shafting Bearings and Supports," read before the Liverpool Engineering Society recently, Mr. J. Watson drew attention to these problems, and from the

wealth of his experience indicated some of the ways whereby they had been satisfactorily solved. Not the least interesting part of his paper dealt with the difficulties of lubrication of the shaft bearings and the thrust bearing which have arisen by the substitution of turbines for reciprocating engines. The vibration set up in the shaft by the reciprocating resulted in the lubricant in the bearing finding its way between the shaft and the white metal to a greater extent than is the case with the smoother running turbine machinery. Thus while in the crankshafts of reciprocating engines bearing pressures between 300 pounds and 400 pounds per square inch can be safely employed—on crossheads 1,200 pounds per square inch is safe—owing to the reciprocating pulsation enabling the oil to get on, and the film to be maintained between the surfaces, the line shaft bearings have only been designed to take between 30 pounds and 50 pounds per square inch. The author advocates the adoption of the Michell principle in the design of bearings, either by easing away the white metal to within a short distance of the ends of the bearing, so that the oil may be wedged under the shaft, while in addition there should be no sharp edges on the bearing to scrape the lubricant off, even the gutters or oil grooves being eased away at the edges to avoid this. He further suggested the adoption of the Michell type of bearing for the line shafts as being better adapted for the purpose than either roller or ball bearings and in view of the fact that the Michell bearing requires only a small surface because of the high pressures that can be carried and because of the facility with which it will adapt itself to all conditions due to deflection of the shaft, etc., the suggestion certainly seems worthy of close examination. The advantages which have followed the adoption of the Michell thrust bearing are too well known to need repetition, but it is worthy of being noted that with multiple ring thrust blocks the expedient of cutting away a considerable portion of the surface of each of the horseshoe faces in wide grooves across the face, the edges of the grooves being rounded off, enabled thrust bearings which hitherto could not stand up to their work, becoming heated and damaging the white metal faces, to work cool and smoothly despite the fact that about one-third of the total surface was removed.

One of the details requiring the maximum amount of care in designing is the stern tube. At this point not only has the effect of the overhung portion of the shaft carrying the propeller to be considered, but there is the effect of the variation of depth to which the propeller is submerged when running in a seaway, and also the possibility of being struck by a wave when out of the water. The size of the propeller shaft depends upon the size of the propeller, but while the size and weight of the propeller cannot well be modified for given conditions, the length of the propeller boss can be kept as short as possible in order to reduce the bending effect which is resisted by the stern tube bearing. It seems hardly necessary to urge that the propeller must be absolutely rigidly fixed on the shaft in order to prevent vibration, but the use of a stepped feather key as advocated by the author is worthy of notice. In the stern tube itself the usual practice of fitting a brass liner working on strips of lignum vitæ is not the best method that can be adopted, particularly for large shafts where the difficulty of fitting the liners is considerable and where the wear is often found to amount to as much as ¼-inch to 5/16-inch in two years. There is also the possibility of corrosion being set up by the action of the sea water on the brass and steel. We have recently drawn attention to this problem, and the author is at one with us in recommending the adoption of a steel tube, white metal lined, for carrying the bare shaft through some form of gland whereby the ingress of sea water is prevented, some system of lubrication being provided to keep the sea

water from the shaft, and also to reduce friction. Some actual examples of white metal lined stern tubes were referred to which have run for years without any serious trouble at all. It is apparent, however, that the problem of designing the bearings for the propeller shaft, both in the tunnel and at the stern, is not yet satisfactorily solved, and there exists here a wide field for the application of investigation and research.—"Shipbuilding and Shipping Record."

SUPERHEATING WET STEAM.

It is sometimes stated that the function of the superheater is first of all to dry the steam that comes to it wet from the boiler, and then to raise its temperature through a pre-arranged number of degrees above that which obtains in the boiler. This, however, is an erroneous point of view, for according to the amount of wetness with which the superheater has to deal, so is its efficiency as a superheater reduced and so in consequence is the efficiency of the engine reduced. Thus, considering boiler steam at 200 pounds per square inch gauge pressure, its latent heat is about 838 British thermal units per pound, so that 1 per cent of moisture requires 8.38 units of heat in the superheater to dry it. Hence, taking the specific heat of superheated steam as 0.55 British thermal units per pound per degree Fahrenheit, this amount of heat is capable of raising the temperature of steam through about 15 degrees Fahrenheit. Thus, if the boiler is fitted with a superheater capable of giving 100 degrees Fahrenheit of superheat, if the steam enters the superheater containing only 3 per cent of moisture the superheat would be reduced to 55 degrees Fahrenheit, while the superheat would be entirely eliminated if the moisture in the steam reached about 7 per cent. When it is remembered that the steam consumption of the engine may be considered as being reduced by about 1 per cent for every 10 degrees of superheat, it will be seen how great is the effect of moisture on the superheater on the steam consumption of the engine. While, of course, under ordinary circumstances it is impossible to prevent wet steam from passing from the boiler, it is obviously of the greatest importance that steps should be taken by fitting anti-priming pipes or separators to ensure that the steam entering the superheater is as dry as possible.—"Shipbuilding and Shipping Record."

THE DESTROYER *TYRIAN*.

The destroyer *Tyrian*, recently completed by Yarrow & Co., at Scotstoun, achieved on trial the remarkable speed of 39.73 knots. She is practically identical with the *Mounsey* and the *Turquoise*, but has beaten the former by over half a knot and the latter by over one-tenth knot. The *Mounsey* saw active service and rescued in a gale of wind on October 6th, 1918, 696 persons from the cruiser *Otranto*. The *Turquoise* ran her trials last March.

The length of the *Tyrian* is 273 feet, her beam 25 feet 7½ inches, her depth amidship 16 feet 3 inches, her displacement fully loaded 1,060 tons and her complement 73 men. She carries an armament of three 4-inch quick-firing guns, one two-pounder anti-aircraft gun and two sets of double 21-inch torpedo tubes.

The machinery consists of two direct-drive turbines of the Brown-Curtis combined impulse and reaction type, constructed by Yarrow & Co., provided with steam by three boilers of the Yarrow latest oil-burning type, with heating surface of 22,017 square feet, of which about one-fifth is superheating surface. The superheaters are of the Yarrow single-

drum type, and are fitted on one side only of each boiler, an arrangement which has proved highly successful. The exceptionally good results obtained with this boat are no doubt to a large extent due to the adoption of superheaters.

Weir's closed feed system is fitted in conjunction with two "Uniflux" type condensers and a high vacuum is obtained. In this system air pumps of the old type are dispensed with, and in their place are installed two turbo-driven extractor pumps and ejectors. The circulating pumps were supplied by Drysdale & Co., and the forced lubrication pumps, oil fuel pumps and feed pumps are all of Weir's make. Forced draught fans, of which six are fitted, are of the Yarrow-Terry turbo-driven type, with vertical spindles, and their effectiveness was clearly shown on the trial, there being, we are informed, no smoke at even the very highest powers.

On the official four hours' full-power trial, of which a few figures are given below, the *Tyrian* carried her contract load—fully armed and equipped and with sufficient fuel on board for a run of 1,000 miles at an economical speed.

	On measured mile.	*Four hours.*
Boiler pressure	260	260
Superheat, degrees Fahrenheit	100	100
Revolutions per minute	721	715
Speed, knots	39.72	39.4
Radius of action at a speed of 15 knots	3,260 nautical miles	
Radius of action at full speed	650 nautical miles	

One of the outstanding features of the *Tyrian* and sister ships is the remarkably good maneuvering quality they possess. At full speed they turn in a circle 500 yards in diameter, and at lower speeds in a considerably smaller circle.—"The Engineer."

FLOATING GEARS FOR NAVAL MACHINES.

It will be recalled that during the war certain battleships of the Allied Navies were provided with small biplanes which were flown from runways on the turrets. These machines were of the land type, equipped with wheels. Obviously, the pilot had to land in the water when his fuel became exhausted, and the heavy machine was apt to sink in a very short space of time. These facts led Squadron-Commander Busteed of England to consider the question of devising light flotation arrangements which could be attached to the normal land machine and which would enable it to float right side uppermost, and eventually to produce the emergency flotation gear with which his name is now associated. In its original and simplest form this gear consisted of balloon fabric, circular in section when inflated, attached to the lower wing of any ordinary type of biplane between the leading edge and the front spar. These bags were normally deflated and folded flat against the lower wing surface, to which they were held by a fabric flap permanently fastened along the leading edge of the wing and clipped to the front spar by eyelets which could be simultaneously released by pulling a string from the pilot's cockpit. When thus folded, continues *The Aeroplane*, the air bags merely slightly thickened up the front portion of the wing section, and produced no noticeable effect on the machine's performance. When it was desired to alight on water, the pilot first pulled the string releasing the flap, and then by turning on compressed air from a standard compressed air starting bottle into an air injector which communicated with the bags, inflated the latter to their full capacity. The inflated bags provided a large buoyancy ahead of the

center of gravity of the machine, and in conjunction with fuselage bag behind the center of gravity kept the machine afloat in its normal attitude.—"Scientific American."

OIL FUEL AND BOILER EFFICIENCY.

Apart from the usual advantages attaching to the use of oil fuel such as decreased labor staff in the stokehold, facility of bunkering, etc., the fact should not be lost sight of that, owing to improved circulation of the water in the boiler, the efficiency of the boiler, that is to say, the percentage of the heat of the fuel which is actually given to the water in the boiler, is considerably increased. In the case of the ordinary marine boiler having cylindrical furnaces the fire bars are removed, and the burner is located at the center of the front of the furnace. It follows, therefore, that the furnace is heated all over its surface, and, since the bottom part of the furnace is heated, it follows that the water in contact with this is also heated, and rising to the surface owing to decrease of density is replaced by cooler water. It is well known that with coal-fired boilers the bottom part of the boiler often remains cold for many hours, and perhaps for a day or two, after the fires are lighted. With oil fuel this is prevented, and the resulting improvement in the circulation greatly increases the efficiency of the boiler and at the same time reduces the possibility of local strains. In a recent test of an ordinary cylindrical marine boiler with oil fuel an efficiency of over 83 per cent was obtained, a figure which it is safe to say would be impossible with ordinary coal hand-fired.—"Shipbuilding and Shipping Record."

SUPERHEATED STEAM IN TURBINES.

It is generally estimated that the gain in economy due to the use of superheated steam is about 1 per cent for every 10 degrees of superheat. Thus, if steam having 150 degrees of superheat is employed, the resulting gain should be 15 per cent, irrespective of whether the steam is employed in a reciprocating engine or a turbine. There are certain disadvantages which follow the improper use of superheated steam, the two most important of these being the effect of high temperature on the castings of the engine, causing distortion, and the difficulty of lubrication. In the turbine the effects of distortion may be particularly serious in view of the fine clearances which have to be adopted with certain types of turbine, and it may be stated that one of the reasons why the high-speed impulse type of turbine is adopted is because with this type, owing to the high velocity of the steam, the clearances can be made more generous both in the axial and the radial direction. It is, however, advantageous to keep that portion of the turbine which is exposed to the effects of highly superheated steam as small as possible, and for this reason in the first set of nozzles the fall of pressure is often about two-thirds of the total fall between boiler and condenser, so that on leaving these nozzles the temperature of the steam has fallen to such a degree that its effects are greatly reduced.—"Shipbuilding and Shipping Record."

AMERICAN BUREAU OF SHIPPING APPROVES THERMIT WELDING FOR MARINE REPAIRS.

An important development of thermit welding in American shipyards is anticipated by the recent approval by the American Bureau of Shipping of the thermit process for welding stern frames, rudder frames, and other heavy sections on ships registered under their classification. The

only qualification is that this Bureau be notified sufficiently in advance to have a surveyor in attendance during the welding operation as well as to inspect and test the weld when completed.

While the thermit process has been used since 1903 for making marine repairs and has a great many successful welds of this nature to its credit, the process was never officially approved by the American Bureau of Shipping and most of the repairs were made on vessels not classed by them. It is due entirely to the unbroken record of successful marine welds that the Bureau now accords its official sanction to the process. According to a statement by the Metal & Thermit Corporation there has never been a single failure of a thermit marine weld so far as it has been able to ascertain in all the years that the process has been used under this company's jurisdiction.

Now that the United States promises to have one of the largest merchant marines in the world, and as practically all of the ships which have recently been constructed, and which will be constructed in the future, will be registered with the American Bureau of Shipping, the recognition of the thermit process by that Bureau bids fair to result in many important thermit marine welds from now on.—"International Marine Engineering."

THE FRENCH ABANDON STEAM-DRIVEN SUBMARINES.

The French, who were among the first to develop steam-driven submarines, are building no more of them, being convinced, according to J. B. Gautreau, that steam as a motive power does not lend itself to that rapidity of submersion, which is a fundamental asset of the submarine. According to this authority, the former troubles in building and operating Diesel engines were completely overcome during the war. The latest French class of 1,050 tons, originally designed for 4,000 horsepower engines, have instead been equipped with two 1,300 horsepower Diesel-Sulzers, giving a surface speed of about 18 knots and a radius of 7,000 miles at cruising speed.—"Scientific American."

ECONOMY OF ELECTRIC DRIVE.

A comparison of performance of the motive power of the *New Mexico* with that of other battleships shows marked economy in favor of the electric drive. Thus, at 12 knots' speed, the consumption in tons of oil per day was for the *New Mexico* (electric drive) 75 tons, as compared with the *Arizona* for her cruising turbines, 100 tons and main turbines, 118, and the *Mississippi* for her cruising turbines, 99 tons, and for her main turbines 115 tons of oil per day. At 19 knots, the consumption of the *New Mexico* was 263 tons, of the *Mississippi* main turbines 308 tons, and of the *Idaho*, main turbines, 310 tons per day. Similar economy was shown by the electric drive at the intermediate speeds.—"Scientific American."

INTERNAL COMBUSTION FOR NAVY VESSELS.

In his work, "Les Enseignements Maritime de la Guerre Anti-Germanique," Contre-Amiral Daveluy, of the French navy, who presents his conclusions as to various phases of the naval operations of the Entente powers in the World War, expresses the interesting belief that the fleet of tomorrow will be vastly different from that which fought the great conflict. He asserts that certain classes of ships are bound to disappear, while others will necessarily be compelled to undergo radical changes. He

hopes that the French navy will distinguish itself, among other particulars, along lines affecting the form of motive power and also the exterior aspect of fighting ships. He very strongly advocates that in all vessels of that navy internal combustion be substituted for steam. From the military point of view the disadvantages of steam, he says, are multitudinous. Only an officer who has made cruises in search of an enemy or who has otherwise operated on the high seas can fully realize the great distance at which smoke from another ship can be discerned, or, as ships in time of war have always endeavored to do, can see while at the same time seeking to conceal their own presence. In order to overcome the first difficulty, the Admiral writes, and to accomplish the other object it is indispensable that ships be given a motive power by means of which their presence may not be revealed to the enemy long before the hulls of the ships themselves may be discerned above the horizon, either from the deck of the observing vessel itself or from watchful aircraft. Another great advantage which ships whose motive power is internal combustion possess over those propelled by steam, he observes, is that the former require neither boilers nor condensers, which occupy much room and add to the dead weight; and also that the ships are not filled up with coal, also making for greater weight; and while of the same tonnage are consequently much less encumbered than are ships using steam power. This last consideration, he points out, is a very important one in view of the fact that under such conditions it is no longer necessary to place weight where the shock of the exploding enemy torpedo is susceptible of determining the explosion of ammunition on the vessel attacked. Another point in favor of liquid fuel, he claims, is the ease with which a ship may be refueled, a particularly great advantage over ships burning coal and making long cruises, and where the taking in of coal is often a difficult matter. For some years the question of internal combustion has been under consideration by naval authorities, he recalls, not alone for small craft but in the case of cruisers and other craft of greater tonnage. The objection has been made that France does not possess sources of oil supply, and while this is true, the noted naval critic admits, yet possessing coal mines it was able to contribute its share in naval operations during the war. Furthermore, he concludes, it is by no means certain that there are no oil fields in Algeria, a French possession.—"Army and Navy Journal."

INVESTIGATION OF FATIGUE OF METALS.

An investigation of Fatigue Phenomena in Metals under repeated stress has just been started under the joint auspices of the National Research Council, Engineering Foundation, and the Engineering Experiment Station of the University of Illinois. The Engineering Foundation is providing $15,000 a year for two years for this investigation and the Engineering Division of the National Research Council is acting in an advisory capacity, largely through its Committee on Fatigue Phenomena in Metals. The experimental work is being done in the laboratories of the Engineering Experiment Station of the University of Illinois, under the immediate direction of Professor H. F. Moore, Research Professor of Engineering Materials and Chairman of the Committee above mentioned.

Plans are laid for a two years' program of tests, and apparatus and material are already arriving for the tests. It is hoped to secure a considerable amount of data on tests of various metals including a number of tests of each metal to 100,000,000 reversals of stress. It is hoped to study the various short-time physical tests which are used for metals—

such as the impact tests, magnetic analysis, and short-time bending tests—to see whether any of these give reliable indices of the ability of the metal to resist fatigue under millions of repetitions of low stress. It is hoped that some reliable commercial test for this important property may be developed by this investigation.

A test party of four or five persons is being organized and the University of Illinois is fitting up a special laboratory with about 2,500 square feet of floor space for the use of this investigation.

FUEL INJECTION IN DIESEL CYLINDERS.

For very many reasons the Diesel engine is recognized as being particularly suitable for the propulsion of merchant ships, and yet despite all these we are still a long way from seeing the Diesel engine widely installed for this purpose. It is unnecessary to enter here into the advantages of the Diesel engine, they are well known to marine engineers, and have been reiterated often enough. There are, on the other hand, only two main reasons which mitigate against its extended adoption on board ship, and they are its comparative unreliability and the short life of certain of its essential parts. Many marine engineering firms, now that they are free to develop their businesses in new directions, are taking up the design and construction of Diesel engines, and it is certain that in every new class of engine built there will be embodied attempts to overcome the two drawbacks referred to above.

One of the most important details of the Diesel engine, and the one which is perhaps the most fruitful source of failure, is the fuel injection system. It is well known that in the Diesel cycle of operations the fuel is forced into the cylinder where, as a result of the heat of compression of the air already in the cylinder, it automatically ignites, the heat thus liberated being responsible for the work done during the succeeding stroke of the piston. It is obvious that in order to ensure complete and even combustion that the fuel must be finely divided as it enters the cylinder, and, moreover, that it must become thoroughly mixed, after it enters, with the air already in the cylinder. There are thus two conditions essential to efficient fuel injection, namely, atomization and turbulence, and in order to ensure that these conditions shall be fulfilled, the fuel is forced into the cylinder through a fuel valve so constructed that it breaks up the fuel into a fine spray and delivers it into the cylinder with such a motion that it is spread throughout the combustion space and becomes intimately mixed with the air that is necessary for its combustion. It must not be forgotten, however, that the fuel used on ships propelled by Diesel engines is usually thick residual oil, that is to say, natural petroleum as it issues from the ground after the lighter and more valuable fractions, such as petrol and paraffin, have been distilled off. This residual oil, or "fuel oil" as it is termed, is a viscous black fluid at ordinary atmospheric temperatures, and steps have to be taken to ensure that it shall be thoroughly atomized at the fuel valve.

Two systems have been devised for ensuring complete atomization of the fuel oil; first, the air blast system in which, as its name implies, a blast of air under pressure is employed to force the fuel into the cylinder against the compression pressure therein and at the same time to break up the fuel into a fine spray, and second, the solid system, in which the fuel oil under pressure is forced through a valve so arranged that it is broken up into fine particles before entering the cylinder. An examination of the various types of Diesel engine already manufactured shows that the air blast system is more generally used than is the solid system,

although both systems are employed by different well-known engine builders and each possesses advantages which cannot be claimed by the other. With the blast system an air compressor has to be fitted capable of running at anything up to about 750 pounds per square inch, since not only has the fuel got to be atomized, but it has to be injected into the cylinder against a compression pressure of usually between 450 and 500 pounds per square inch. Of course, an air compressor has to be installed for providing air for starting purposes, but with the air blast system of fuel injection the air compressor must be continually running, whereas with the solid system, the compressor is only run occasionally in order to keep the starting air bottles fully charged. This must be considered as advantageous to the solid system, since experience shows that the continual running of an air-compressor at high pressures is a frequent source of breakdown. With the solid system a very high pump pressure is required, in one type of engine this being no less than 4,000 pounds per square inch; but of course the volume of fuel dealt with is very small.

The use of air as the vehicle for conveying the fuel into the cylinder has the undoubted advantage that it ensures that the tiny particles of fuel shall be surrounded with air required for combustion, but against this has to be set the fact that the sudden expansion of the air on entering the cylinder, due to fall of pressure, lowers the temperature of the air in the vicinity of the fuel, thus tending to retard combustion. This of course is avoided with the solid system and as a result it is found that the maximum compression pressure which must be attained in the cylinder of an engine with air blast injection is higher than with the other system. From the mechanical point of view this is a disadvantage, since it leads to greater stress in all the working parts of the engine, but theoretically the reverse is the case, since it can be proved that the thermal efficiency of an engine depends only on the rate of compression of the working substance and therefore the higher the final compression pressure, the higher is the theoretical efficiency of the engine.

It will be seen, therefore, that each system has its advantages and its disadvantages, and it is only by patient experiment and research and by a careful study of the practical running of engines in every-day service that the means of overcoming the disadvantages will be discovered. But these and many other problems in the design and construction of Diesel engines are being faced and solved, and no doubt time and study will lead to the gradual improvement of this very efficient type of prime mover.—"Shipbuilding and Shipping Record."

DEFINITION OF ENGINEERING.

Not an Easy Task, According to Gardner S. Williams.

(A complete and workable definition of an engineer or of engineering has given rise to much discussion.) Writing on another subject in *The Ohio State Engineer*, Gardner S. Williams digresses on this mooted matter as follows:

The first one is a paraphrase of Tregold's old definition, and reads:

"Engineering is the science and art of directing the great sources of power in nature to the use and convenience of man."

Note the introduction of the word "science."

The second is:

"Engineering is an art and science. It is a science insofar as physical laws are its basis, and an art insofar as in the application of these laws, and the things designed and constructed develop the spirit of progress,

the creation of wealth, and the wellbeing of all peoples. Engineering is generally divided into four major divisions, viz., Civil, mechanical, electrical and mining.

"The practice of engineering requires knowledge of physical forces and the materials of nature. The professional engineer is one who by reason of special training, education and experience, is qualified to design and direct the construction of engineering work in one or more of the major divisions of engineering."

The third definition which was submitted is:

"Engineering is the creative science and art of applying economically the materials and forces of nature to the use and convenience of man."

That is again a paraphrase of Tregold's definition.

The fourth definition which was submitted, reads as follows:

"Engineering is the science of industrial effort and the science and art of applying this effort for the welfare of the public. An engineer is one versed in the science and art of industrial effort made for the purpose of public welfare."

Now I submit to you that, in spite of the acumen, the learning and the experience of the dozen or less gentlemen who are engaged in the framing of those definitions, still they do not fit. They do not meet the requirements that we have to have if we are going to really make an intelligent definition of the engineer or of engineering so that it can be applied in an act of a legislature to define who is entitled to practice under that act.

The fact is, gentlemen, that the underlying spirit of engineering is something that is almost indefinable. The word engineer did not come from engine. If we go back to where it did come from, we find that it came from the same root as genius. If we follow that back, we come to the genii, the spirit of things.

To my mind there should be something in the definition of the word engineer that does not appear here. All these things belong there, they are all part of it, but you have not gotten the real idea yet. When some remarkably adroit piece of parliamentary work is done, some act is passed through a legislature, or through a Congress that it was not thought possible to be passed, we say, "Who engineered that?" When you find some combination of interest in the mercantile world or in commercial affairs or banking, you wonder who it was who engineered that thing.

There, gentlemen, is the idea. It is that spirit, that guiding impulse, that something that is behind and directs the forces of nature. And as I said once this evening, the greatest force in nature is man. When you get the true definition of engineering and of the engineer, it must somehow incorporate this idea. That is as far as I can go with it. I confess that no one has been able to write a satisfactory definition of either engineering or the engineer.—"Cleveland Engineering."

PLASTIC-ARC-WELDING—ITS PAST AND FUTURE IN SHIP REPAIR AND CONSTRUCTION.

By J. O. Smith.

When the matter of welding in connection with ship construction is considered, immense possibilities immediately suggest themselves. It has been definitely determined by exhaustive technical study and experiment that welding can be satisfactorily employed in ship construction, that ship plates joined by welding will be as strong as, or stronger than, the original metal at the welded joint, and that welding can be employed for ship construction work at a saving of 25 per cent in time and 10 per cent in material, as compared to riveting.

In actual figures, as determined by experiments of the Emergency Fleet Corporation's electric welding committee, it was determined that by welding in the case of a 9,500-ton ship the saving in rivets and overlapped plates would amount in weight to 500 tons, making it possible for the ship to carry 500 tons more cargo on each trip than would be possible if the ship plates, etc., had been riveted instead of welded.

An investigation by the electric welding committee of the Fleet Corporation has definitely established the following points:

That electrically welded ships can be built at least as strong as riveted ships.

That plants for ships designed to be riveted can easily be modified so as to adapt them for extensive electric welding, and thus save considerably in cost and time for hull construction.

That ships especially designed for electric welding can be built at a saving of 25 per cent over present methods and in less time.

An electrically welded ship is credited with many advantages over a riveted ship. In a 5,000-ton ship about 450,000 rivets are used. A 9,500 deadweight ton ship requires 600,000 or 700,000 rivets. By the welding process the saving in labor on the minor parts of a ship is reckoned at from 60 to 70 per cent. On the hull plating and other vital parts, the saving in labor, cost and time of construction by welding is conservatively placed at 25 per cent.

That electric welding will some day largely replace riveting is also the judgment of the electric welding committee, which is composed of eighty-two of the leading experts in both the electrical and metallurgical branches of the welding field.

Considerable investigation of the subject of welding instead of riveting has been made in England by Lloyds' Register of Shipping, particularly with regard to formulating rules for application to the electrical welding of ships. As a result of the investigations and experiments by the society's technical staff, it was determined that the matter had assumed such importance as to warrant the formulation of provisional rules for electrically welded vessels, and these have been issued for the guidance of shipbuilders by Lloyds' Register.

The experiments conducted in England followed three well-defined lines of investigation: Determination of ultimate strength of welded joints, together with their ductile properties; capability of welded joints to withstand alternating tensile and compressive stresses, such as are regularly experienced by ships; and microscopic and metallurgical analyses to determine if a sound fusion was effected between the original and added metal.

It was determined that the tensile strength of the welded joints was from 90 to 95 per cent of the original plates, as against a strength of from 65 to 70 per cent in riveted joints, showing a margin of 25 per cent increased strength in favor of the welded joints.

The result of the tests of the elastic properties of welded joints determined that there was a slight difference in favor of the riveted joint, but the art of welding has made such great strides recently that it is now believed entirely possible to make a welded joint in ship plates that will stand as great a number of reversals of stresses as a riveted joint.

Microscopic and metallurgical analyses have determined definitely that a good, solid, mechanically sound weld was made between the original and the added metal, the two metals having been fused together so perfectly that no line of demarcation could be seen.

The rules so far promulgated by Lloyds have been necessarily of a tentative nature and will no doubt be modified and enlarged from time to time, in view of the experience that will be gained after a few welded ships have been in service for a time.

It does not require a great deal of imagination, however, to enable anyone to form the opinion that the shipbuilding industry is on the eve of great modifications in constructural lines, and the guidance given the shipbuilding industry by the tests and comparisons so far made will undoubtedly lead to important, radical departures and developments in the industry.

In addition to the increased cost of riveting as compared to welding, it is practically always true that there is a certain percentage of imperfectly fitted rivets, and these have done nothing more than add weight to the ship. The main purpose of a rivet, of course, is to bind two or more thicknesses of plate together, but if the rivet is bent, loses part of its head in the riveting process, or otherwise fails in its proper purpose, there is no method by which such faults can be corrected after the rivet cools. It must be removed entirely if the importance of the riveted part requires a perfect joint, and this is frequently a time-killing, expensive course to follow. When it is considered that a 5,500-ton ship requires approximately 430,000 rivets to bind the various parts and plates and also that many of these rivets are not fulfilling the purpose for which they were put into the ship, it is evident that practically every ship is burdened with a good-sized load of dead, useless weight. Such defective rivets are, in fact, more than a useless weight, in that they are a menace to the ship, for while they have been built into the ship for a purpose and are supposed to be fulfilling that purpose, there is no telling how much the ship has been weakened structurally by their failure.

In many cases, when such leaky rivets are discovered, the present-day method is to weld such defective spots, and this immediately brings up the natural question as to why the plates should not be welded in the first place.

The fact that a welder using a direct-current, low-voltage arc with automatically regulated current is able to make sound mechanical welds in cramped, confined spaces on overhead or vertical walls—in fact, anywhere a man and a wire can go—naturally suggests that welding ship plates together should be the primary operation in shipbuilding.—Extracts from "Pacific Marine Review."

THE DEVELOPMENT OF THE INTERNAL-COMBUSTION ENGINE.

By Charles Baxter, Member Institute of Marine Engineers.

In marine engineering the steam reciprocating engine has in the past held undisputed sway, and along with the steam turbine will undoubtedly hold a prominent position in the future.

Signs are not lacking, however, and at the present time the internal-combustion engine is receiving considerable attention in marine circles, and, what is more, shows every indication of becoming a serious rival to the two previously mentioned prime movers, it being at last looked upon by engineers as a serious proposition.

In the early days of the development of this new prime mover, wild statements were made by its over-energetic sponsors in order to cover up the many faults it then possessed.

It was stated that the reliability was at least equal to the reciprocating steam engine and on most other points with perhaps the exception of the starting difficulty it was said to out-rival its opponent. There is, therefore, no getting away from the fact that these irresponsible statements did an infinite amount of harm, for when the purchaser found they could not be substantiated, the pendulum swung the other way and a period of unnecessary scepticism prevailed which took many years to dispel.

Early engines of this type were very unsatisfactory in many ways, all of which, directly or indirectly, affected their reliability and due to the small sizes in which they were then built, no attempt was made to boom them from a marine point of view, which is perhaps very fortunate for the marine engineer as the development through which all prime movers have to pass to reach the commercial stage, then took place on shore which was in this case a far safer proceeding.

Problem after problem was solved, however, by close application, which incidentally enabled larger sizes to be built, until now we find successful ships of reasonable size, engined with this prime mover running with a regularity which was only previously associated with steam.

These ships, although not very large in either size or number, are rapidly growing in both directions and it is undoubtedly a sign of the times, which augurs well for their success, that marine engineers are beginning to be interested.

The development taking place upon shore put marine engineers rather at a disadvantage, as it was only at intervals that many of them got the opportunity of coming into contact with these engines. They were, therefore, left rather in the dark as to the historical and development side of the study, and when this branch of engineering is taken up it is found that it has already grown to almost gigantic proportions; engines differing widely from each other being used for all manners of purposes ranging from the propulsion of ships to the propulsion of aeroplanes and motor-cycles.

Now although the members of the Institute are chiefly interested in the propulsion of ships, it is a fact that the development of this engine in its different branches all went to form the whole, it being impossible to say where the discoveries and development in one branch cease to influence another.

It will, therefore, be found upon taking up the study of this prime mover that the particular knowledge required is scattered over innumerable text books and technical journals, the perusal of which is truly a formidable task, and it is with a view to helping engineers interested in the subject that the writer has been tempted to offer this paper.

The information given has been carefully compiled during the past few years, and if it saves some of the time usually spent in wading through ancient and modern literature upon the subject, this effort will be amply repaid.

The present paper is not the first one before the Institute upon the internal-combustion engine, many valuable ones preceding it, which are well worth the time spent in perusal, and if the discussion upon the present one is as practical and enlightening as those on its predecessors much valuable information will come to light, the views of members always meriting considerable respect.

Historical.—The very early history or origin of this engine is rather obscure and seems to have begun with a period of speculation, before anything was done, the Abbe Hautefeuile described an engine in the year 1678; a partial vacuum caused by burning gunpowder in a cylinder, raising water, the resulting gases being cooled. Gunpowder, in small quantities, was exploded in a cylinder, the pressure being allowed to escape through non-return valves; upon the gases cooling and the pressure falling below that of the atmosphere the piston was forced down by atmospheric pressure.

According to patent records which are something of a guide in the matter, a Robert Street, of this country, in May, 1794, described an engine which worked by turpentine.

Other atmospheric type engines, such as that by Samuel Brown, 1823, a beam engine, were made, in which the working depended upon the

exploded charge being cooled and so forming a vacuum, allowing the atmosphere to do the work.

The first engine to attain any success, however, was that of Lenoir, 1860; this was a double-acting engine, very similar to the steam engines of that day.

The impetus given to the fly-wheel allowed the engine to give off a certain amount of power and tided it over the idle stroke. The maximum pressure was in the region of 50 pounds per square inch, and the consumption is said to have been 95 cubic feet per indicated horsepower hour.

An engine afterwards made by Hugan seems to have been of better mechanical construction, as the consumption was reduced to 85 cubic feet per indicated horsepower hour, whilst an atmospheric type engine by Otto & Langen further reduced the consumption to 44 feet by allowing the mixture to come in below a slightly-raised piston and exploding it, the piston being rapidly sent upwards like a projectile, thus giving favorable conditions by rapid expansion, the weight of the returning piston along with the atmosphere, doing the work. The feature of Otto & Langen's engine was that the piston was free on its upward stroke and was connected to the crankshank on its return stroke by a free wheel clutch. The maximum pressure was about 56 pounds per square inch, the consumption in large sizes falling to 30 cubic feet.

It may be of interest to note that an engine by Samuel Brown was run experimently in a boat on the Thames, this being, so far as the writer is aware, the first internal-combustion engined boat.

The next step of any note in the chain of events was the discovery that if a charge of mixture be drawn into the cylinder, compressed by the piston, exploded, thus doing the work upon the piston and driven out on the piston's return, that this formed a much more efficient cycle.

Four-Stroke Cycle.—The cycle of events was thus completed in four strokes, from whence it derives its name, it being without doubt the point at which the real history of the internal-combustion engine began.

It may seem strange that anything can be gained by compressing the mixture previous to ignition, but it is found in practice that there is a great gain in efficiency, the mixture in modern engines being compressed to as high a pressure as practicable, as will be explained later.

Two-Stroke Cycle.—The two-cycle engined also compresses its mixture previous to exploding it and is now in extensive use, the cycle of operations being thought out by Sir Dugald Clerk. The engine completes its cycle, of course, in two strokes. The engine has its expansion, exhaust, and inlet strokes all in one, so to speak, the other stroke being for compressing the charge. These engines can be made without valves, and are simple and reliable, being used in great numbers for small craft and motor-cycles.

It should be borne in mind that they give more power than the four-cycle, exploding twice as often, but not twice the power, as a proportion of the stroke is taken up in uncovering ports. These engines will also run in either direction, but as the very small ones are not self-starting, this is not of much consequence and a reversing-gear is provided. They are also not as efficient as the four-stroke, due to some of the inlet charge going out with the exhaust, although where the scavenging is done by air this does not, of course, apply. The uncommon feature about engine is that the inlet charge drives out the exhaust, but this is found in practice to be quite satisfactory, the only precaution being the placing of a wire gauze in the transfer port to prevent accidental explosion in the crank chamber. Another point is that when running up a partially-closed throttle the cylinder is not quite filled with mixture and miss-fires, the next charge filling it and allowing the explosion to take place. It is possible for this to happen with great regularity, the explosion every

other stroke being known as four stroking, but normal functioning is at once resumed when more throttle is given.

Four-Cycle Diesel.—In this type a charge of air is drawn in on the induction stroke and compressed on the compression stroke to give it a temperature in the region of 1,000 degrees F., which is higher than that required to burn the fuel.

At the end of the compression stroke the fuel valve opens and oil is injected by compressed air, thus burning automatically, the expansion and exhaust strokes taking place as in all four cycle engines. The fuel is injected by air in order to pulverize it and the extended burning period gives a diagram more like that of a steam engine.

All kinds of heavy fuel are used successfully in these engines and no ignition apparatus is required, but the heavy strains set up have been a formidable obstacle to designers.

Two-Cycle Diesel.—This is identical with the two-cycle engine previously described, but on the Diesel system. Assuming the piston to be at the end of the expansion stroke, a charge of air is admitted under pressure, driving out the burnt gasses and filling the cylinder, the piston then compresses the air to give the high temperature required, the fuel being admitted, burnt, expanded, and then driven out by the next charge of air.

Semi-Diesel.—This is an engine coming into extensive use, because it practically works upon the Diesel principle but avoids the higher compression pressure. It is also sometimes named by its makers the "Hot Bulb Engine," this term being considered by some to be appropriate, the Diesel cycle being slightly modified.

The cylinder is water jacketed in the usual way with the exception of the hot bulb, which is thus allowed to attain considerable temperature. A charge of air is taken in on the induction stroke and compressed on the next stroke to quite a reasonable pressure, the ignition of the oil taking place by it being injected into the bulb, the heat of which augmented by the heat of compression is sufficient to burn the oil.

These engines may, of course, be constructed to operate upon either the two or four-cycle principle, but by far the greater number operate upon the two-cycle principle, the fuel being injected on the solid system, i.e., by pump without compressed air.

Review.—It will be found that although the engines met with differ widely in detail and arrangement of parts, they may all be classed under one of the previously-described headings. It is difficult to classify them according to their uses as certain types of engines are found in many spheres, but the following will give some idea of their arrangement in this respect.

Two-Cycle Engines.—Motorcycles, small craft, large engines operating upon blast-furnace gas, lighting sets, etc.

Four-Cycle Engines.—Motorcycles, cars, stationary engines, aeroplanes, and airships.

Two and Four-Cycle Diesel Engines.—Marine and generating station work.

Semi-Diesel Engines.—Small craft, etc., where simple operation is imperative and the speed is fairly constant.

Other Cycles.—From time to time other cycles make their appearance, such as the six-cycle, where a charge of mixture is inducted, compressed, exploded, exhausted, then a charge of clean air inducted and then exhausted, the idea, of course, being to get rid of all products of combustion. These, however, do not seem to be put to any commercial use, but a cycle proposed by Mr. Durtnall, one of our members, is interesting and should be noted.

The vacuum at the end of the admission stroke gives a cushioning action and the expansion line falling to atmospheric pressure would apparently give a high theoretical thermal efficiency.

Compounding.—Attempts have been made at compounding internal-combustion engines, but without much success, the power derived from the L.P. cylinder hardly balancing the extra frictional losses.

Double-Acting Engines.—These are constructed by some makers in very large sizes for operating upon such fuels as blast furnace gas, the general lay-out greatly resembling steam practice, some types having their cylinders arranged in tandem.

Operation and Construction.—Cooling Pump.—Water jackets are fitted to cylinders in order to keep the temperature within practical lubrication limits, about 200 degrees F., the circulation being promoted by means of a pump, often of the centrifugal type, or by means of a connection termed Thermo Syphon. In this case particular care has to be paid to pipe resistance, having the pipes of large diameter and all bends of easy radius. In large engines, valves, pistons, and rods are made hollow and water circulated through them.

Cooling Air.—Small automobile and other type engines are often air cooled, fins being cast on the cylinders to assist radiation.

Radiators.—Where only small quantities of water are available, radiators are provided to cool the water, often consisting of gilled tubes through which the water is circulated, a good air draught being produced by a suitable fan.

Cooling Hopkinson Method.—Professor Hopkinson of Cambridge carried out some research work upon cooling and found that he could quite successfully cool engines by spurting jets of fresh water upon the parts inside the cylinder which were likely to get too hot, such as the exhaust valve, thus keeping them at a reasonable temperature and allowing the engine to continuously function normally. This system is interesting as it differs widely from any current practice, but so far as the writers' knowledge goes it has not yet been adapted commercially.

Lubrication.—No startling innovations are noticeable in this respect with the exception of the small high-speed type, which has forced feed through hollow crankshaft and connecting rods, the pressure used often being high, about 40 pounds per square inch. Very small two-cycle crankcase compression engines are lubricated by mixing the oil with the petrol in the fuel tank, but the medium and larger sizes are fitted with a more positive system such as by gear or plunger pump.

Starting.—The starting difficulty is a great drawback, which applies to all types of internal-combustion engines, and all manner of means have been tried to remedy the defect. One idea used on stationary engines is to put the engine upon the firing stroke, pump in a charge of mixture by hand, and then ignite it. Many of them, like the one just described, are tedious and rather uncertain and a method extensively used is by means of compressed air.

This consists of a rotating disc valve positively driven from the engine and timed to deliver air under pressure to each cylinder as it comes upon the firing stroke, the air working the cylinder as in steam practice. It should be noted that the air steams the cylinder on its firing stroke and is exhausted in the usual manner, the inlet and compression strokes not being interfered with. A non-return valve is fitted to the air pipe at each cylinder, so that when the engine takes up the firing the valve closes and prevents the explosion pressure entering the air pipe, the air then being shut off by hand. Easy starting in large engines is obtained by sliding a differently profiled cam into position which reduces the compression pressure by delaying the closing of the inlet valve until the piston has traversed part of the compression stroke, thus returning to the induction pipe a proportion of the mixture taken in. Small automobile type engines are very often started by means of an electric motor supplied by current from an accumulator, many makers fitting this system as standard.

Reversing.—This is often accomplished by sliding the camshaft endwise, bringing another set of cams into operation and restarting in the opposite direction by air. Many types of two-cycle engines reverse by slowing down and then causing preignition by injecting the fuel too early, so causing what is commonly termed a "back fire," which stops and restarts the engine in the opposite direction.

Governing.—Various methods of controlling the speed of engines are in vogue: in the case of Diesel-type engines, for instance, this is done by varying the oil-injection period although the minute variation of the exceedingly small quantity of oil injected per working stroke, entails considerable care in design and accuracy of workmanship, in constructing the pumping apparatus.

Hit and Miss.—Stationary gas engines fitted with heavy fly wheels were for years governed by cutting out an explosion now and again, known as "hit and miss," governing the governor causing the gas valve to miss opening altogether when the speed became too high.

Quality.—Modern times demand a smaller speed fluctuation and so quality governing by varying the gas valve lift is in vogue, which, however, is likely to result in weak and slow burning mixtures with resulting high loss to the cylinder walls thus unfavorably influencing the thermal efficiency, unless carefully arranged.

Quantity.—Governing by controlling the quantity of mixture inducted also has considerable vogue, especially upon engines used upon small craft, where it is universal, the quantity being varied by a throttle in the ordinary way. Governing on the throttle is not good from a theoretical point of view, as it results in the cylinders being only partially filled with mixture, the engines thus running under inefficient conditions, but apart from this it is very satisfactory and often most convenient.

Pressure Fluctuations.—In gas engine work an elastic bag is fitted on the gas line to provide a reservoir of gas and prevent fluctuations in gas pressure, acting as a sort of air vessel.

Indicating.—All engines may, of course, be indicated, an optical type of indicator being used for the high-speed variety, but, generally speaking, this is not done with the same ease and certainty as in steam practice, some type of dynamometer brake being a more reliable method of testing the condition of the high-speed type. The "Clerk" indicator has now been considerably improved and the writer is informed by Sir Dugald Clerk that a description will be published shortly; this will certainly be looked forward to with great interest by engineers interested in the subject. The compression and explosion pressures may easily be obtained by means of the "Okill" indicator, the thimble being screwed down until the movement of the valves can just be detected, the pressure then being read off on the scale.

Silencers.—A study of indicator diagrams will show that the exhaust valve opens some few degrees before dead center and releases the gas at considerable pressure, which results in noise. An expansion chamber is, therefore, fitted on the exhaust line to minimize the sudden fluctuation in pressure, the art of designing this chamber consisting of arranging it so that the gases are gradually expanded without putting back pressure upon the engine.

Cylinders.—The cylinders on small engines are cast solid, the larger types being fitted with detachable heads and separate liners. Many aero engines have their cylinders turned from solid billets, or cast in aluminium with steel liners fitted, a 5-inch cylinder for instance having the aluminium block raised to 340 degrees C. and the liner dropped in, the latter having a finished size 0.005 inch larger than the block.

Pistons.—Large types are fitted with the usual junk rings, the small types being solid, an extra ring being provided near the bottom of the skirt to act as a scraper ring and prevent oil passing the piston and car-

bonizing in the cylinder head. Many makers pin their rings in position to prevent the slots working into line. In high-speed type engines where the losses, due to inertia, become serious, special attention has been given to the construction of lighter pistons, it being found that a reduction of 10 per cent in piston weight, for instance, influences the horsepower developed considerably, being 12 per cent on the higher reaches of the power curve, in an everyday example. Aluminium pistons have been used with great success in many engines, the aluminium getting rid of the heat quickly, due to its higher conductivity, but greater clearance having to be given, due to the higher coefficient of expansion. The coefficient of expansion of iron being 556 by 10^{-8} and that of aluminium by 10^{-8} per degree Fahrenheit. The majority of engines, being single-acting, have their pistons functioning as a crosshead, this being quite satisfactory in practice, aero engines giving no trouble with a piston length over bore ratio as low as 0.6 with a maximum connecting rod angularity of 16 degrees.

Gudgeon Pins and other important parts are now made of high-grade alloy steels, the H section connecting rod being very popular. In stationary gas and oil engine practice the same rules apply to connecting rod bolts as to chains, insurance companies stipulating that they should be annealed periodically.

Gearing.—As the valves on a four-cycle engine are operated every two revolutions a two-to-one gearing must be provided, and this, unfortunately, often gives the engine a very complicated appearance, operating, as it does, a number of other mechanisms such as the ignition, fuel pumps, and starting gear. Neatness of design is now a telling point from a sales point of view and such matters are receiving more attention than hitherto.

Carburetion.—It will have been noted that an engine of the internal-combustion engine type can be run upon any substance which will form an explosive mixture, history telling us that some of the earliest were run upon gunpowder. Modern engines function satisfactorily upon all kinds of fuel, from heavy oil to acetylene gas, the proportion of air, of course, depending upon the value of the fuel. In gas-engine practice a gas value is provided in the air intake which lifts at the same time as the inlet valve thus mixing the gas with the air. In oil-engine practice the oil is often injected directly by a small plunger pump into some part of the combustion head which is allowed to acquire considerable heat, the oil being thus vaporized upon the induction stroke, the part being heated for starting purposes by means of a lamp. For light oil and spirit engines where simplicity is the main point the fuel is drawn in along with the air, upon the inlet valve lifting.

Small petrol and paraffin engines form their mixture in a carburetor. In the case of paraffin, the inlet pipe is heated externally by means of the exhaust, in order to assist vaporization. This type of carburetor is only satisfactory for constant speeds as it can be set to give a correct mixture for any given speed by altering the jet, but it is found that for a variable speed engine such as is used in automobile work, some design is needed which will give an approximately constant mixture at all speeds. The reason why the mixture varies with the speed is because the laws of flow of air and fuel are not the same, the mixture getting richer as the speed increases.

Together these jets correct each other, the mixture remaining practically constant in quality within reasonable limits over a wide range of speed.

Gas Producers.—Many gas engines generate their own supply of gas by means of a gas producer, the engine sucking its supply of air through red-hot fuel contained in a generator and then through a scrubber where it is cleaned. This method of generating gas is very satisfactory, especially from a financial point of view, the cost being very low.

Ignition Jet.—One of the earliest methods of igniting the charge was by means of a gas jet, admitted to the cylinder at the correct moment by a kind of slide valve. The explosion extinguished the jet, which was rekindled by a pilot jet.

Hot Tube.—Jet ignition was soon replaced by the hot tube which consisted of a tube with a closed end screwed into the combustion chamber and heated by a bunson, the mixture, on compression, being forced into the tube and ignited. It worked better than at first may be imagined, some slight adjustment of the firing points being obtainable by moving the burner along the tube.

Firing Valve.—Larger engines were fitted with a firing valve which put the tube into communication with the cylinder at the required moment, thus somewhat controlling the firing point. The early tubes were of platinum and then iron, but later porcelain proved very satisfactory.

Hot Spot.—The ignition of some types of oil engines is after this style, the bulb acting as a tube as well as a vaporizer.

Electric Ignition.—The modern ignition, however, is by means of the electric spark in various forms.

Low Tension.—Ignition by low tension magneto is extensively used for slow-speed work.

The magneto is of the oscillating type and consists of permanent magnets, pole pieces, a shuttle armature wound with fairly thick insulated wire, and springs for returning the armature to its position.

High-Tension Coil.—This type is termed high-tension because the spark is not caused by breaking contact, but is given sufficient voltage to enable it to jump a gap at the sparking plug.

The practical function of the condenser is to reduce the spark at the trembler contacts which would rapidly destroy them, but incidently it increases the rapidity of demagnetization of the coil core, thus causing a rapid collapse of the magnetic field which considerably augments the secondary EMF.

High-Tension Magneto.—This is very similar to the high tension coil with the exception that a battery is not required, the magneto generating its own primary current. The primary winding on the armature generates the low-tension current, the circuit being broken at the correct moment by the contact breaker, which is fixed to and revolves with the armature, striking a stationary cam. This generates the high tension current in the secondary winding, which is collected by a carbon brush and led to the sparking plugs. It should be noted that the armature is nearly always arranged to revolve, instead of oscillate, upon this system, and incorporates the condenser as well as the contact breaker. A safety gap is provided, which the spark takes should the plug wires be disconnected.

Lodge.—This ignition is of the coil high-tension type, the difference being that there are two sparks produced, the spark which takes place in the box and is not used and the spark which is led to the plug.

Review.—It has already been stated that the oscillating low-tension magneto is used for low-speed engines being very popular with this type. The high-tension coil has the advantage that it gives a shower of sparks at starting but carries with it the disadvantage of accumulator charging, and the fact that the sparking is not so accurate, due to the uncertain type of contact maker and the lag in the coil. This system is not much used now, but is sometimes incorporated with the high-tension magneto to facilitate starting, this then being termed dual ignition. In America where much attention has been given to this particular type of ignition it has been redesigned and now gives the same satisfaction as the high-tension magneto.

The high-tension magneto is used extensively today for the ignition of high and moderate-speed engines, the firing being accurately timed and it being easily possible to arrange for the ignition of more than one cylinder by the addition of a high-tension distributor.

The claims made for the lodge ignition are that the B spark, as it is called, is of a very detonating character and will prevent carbonization of the plug, also sparking if the plug should become short circuited. It has been used upon large stationary engines.

It should be observed that in all engines with any pretence to speed it is found necessary to make the spark occur earlier than dead center as the charge takes a perceptible time to ignite, this is done by moving round the contact maker or breaker as the case may be. In very large cylinders more than one plug is often arranged so as to ignite the charge simultaneously at different points.

The amperage of the current passing at the plug in the high-tension type of ignition is very small, due to the considerable step up in voltage, taking place in the transforming apparatus, this fact explaining why a considerable shock can be obtained from a plug lead without fatal results.

The sparking voltage between two brass spheres 0.5 inch in diameter is approximately as follows:

Distance apart in ins.	Voltage.
0.1	5,000
0.5	15,000
1.0	25,000

The distance apart of the electrodes in the cylinder is about 0.020 inch, but it should be remembered that the compression influences the resistance of the gap and also that the facility for the passage of the spark depends upon the area of the electrodes, increasing greatly as one becomes more pointed. In practice they are made of heavy section so as not to cause preignition by becoming incandescent. A difference between coil and magneto ignition with regards to switching off may be mentioned inasmuch that in switching off a coil the primary circuit is broken whereas with magneto ignition the primary winding is short circuited by earthing through a switch.

Fuels.—As previously stated in an earlier part of the paper an internal-combustion engine will function satisfactorily upon many different fuels, the study of the characteristics of which becomes quite a complex matter.

Some of the principal points, however, which interest an engineer are the cost, the heating value, and the amount of deposit which they leave in the cylinder.

The cost, of course, is controlled by many factors and cannot be dealt with here, but an idea of the heating value of different fuels can be obtained from the following tables:

Gases.	B.t.u.'s per cubic ft. Lower value.
Natural Gas	900
Coal Gas	691
Water Gas	285
Producer Gas—Coke	135
Anthracite	145
Soft Coal	145
Coke Oven Gas	545
Blast Furnace Gas	100
*Acetylene Gas	1,480

* 1 lb. carbide = 5 cubic ft. of Gas.

Oils.	S.g. at 32 degs. C.	B.t.u.'s per lb. Lower value.
Crude average	0.870	19,000
Solar	0.870	
Petrol	0.680	19,300
"	0.720	18,500
"	0.760	18,300
Kerosene, American	0.800	18,500
†Alcohol	0.810	11,600
Benzol	0.880	18,200

Mixtures.	Air required for combustion cubic ft. per cubic ft. of gas.
Natural Gas	9.0
Coal Gas	5.25
Producer Gas—Coke	1.00
Anthracite	1.15
Soft Coal	1.25
Coke Oven Gas	5.00
Blast Furnace Gas	0.70
Petrol, maximum power	14.00
efficiency	16.50
Alcohol	11.00
Benzol, maximum power	16.20
efficiency	20.10
Acetylene	12.00

With regard to the deposit question it may be said that all fuels are offenders in this respect, the combustion chamber having to be cleaned out periodically, engines running upon poor fuels collecting a tar-like substance upon the valves, which unless cleaned off prevents their proper functioning. With the highest grade fuels such as petrol the intervals between cleaning are, of course, much longer, the deposit in this case being harder, the limit of time being reached when knocking takes place, due to the coating of carbon, reducing the size of the combustion chamber, or a piece of carbon upon one part assuming such proportions that it causes preignition, due to remaining incandescent.

An accurate idea of the conditions prevailing in the cylinder, besides those observed by the indicator, can be obtained by an exhaust-gas analysis. This is easily done, the apparatus consisting of a frame holding pipettes containing solutions of—Caustic potash to absorb CO_2, alkaline pyrogallol to absorb O, acid cuprous chloride to absorb CO.

The gas is brought into contact with the solutions, the amount of these constituents indicating the efficiency of the explosion, an excess of O for instance indicating weak, and an excess of CO rich, mixtures.

Engine Speeds.—Engines can, of course, be constructed to run at speeds suiting different purposes, but on an average speeds are higher than those used in steam practice, varying from 90 revolutions per minute for marine engines to 3,500 revolutions per minute for automobile racing engines, it being not by any means an easy proposition to control the position of the knee on the speed power curve.

Weights.—Under this heading information is rather difficult to collect, but it may be stated that the engine built by the firm which constructed the

† Can be made from Potatoes, Rye, Starch, etc., Denaturized by the addition of Wood Alcohol.

engines for the airship R34, weighs less than 3 pounds per horsepower, and was used during the war in 55-foot boats for chasing submarines.

Aero engines of a similar type often fall below 2 pounds per horsepower, whilst at the other end of the scale we find two-cycle Diesel engines at 160 pounds per horsepower, and four-cycle Diesel engines at 260 pounds per horsepower. It should be noted that due to the heavy strain set up by the high temperatures and methods of working, Diesel engines are of very robust construction.

Valves.—The slide type of valve previously mentioned, was found to be unsatisfactory and the poppet valve soon came into universal use, being lifted by a cam operated by gearing and returned to its seating by means of a coiled spring. As cast iron was found to withstand the heat well they are often made by screwing a steel stem into a cast-iron head, but with high speeds and compression pressures where valves often operate for long periods at a cherry red heat, it has been found necessary to construct them of special steels which resists the warping and burning action, a tungsten type of steel being often used.

For high-speed work particular attention has to be paid to the shape of the gas passages in order to give the engines a good volumetric efficiency or free breathing capacity, the valve in head system having important advantages over the T headed system.

It must not be forgotten, however, that in a mixture, in which no eddying or whirling is taking place, a far longer period must elapse after ignition before the maximum explosion pressure is reached, than could be possibly allowed in any practicable engine. There is, therefore, a limit in every engine past which it is unwise to carry the free breathing question, if satisfactory running is to be obtained.

The arrangement and design of the valves and passages influences the valve setting, if being found necessary to take advantage of the gas inertia and thus not open and close the valves upon the dead centers.

Valve settings differ considerably, some makers attempting to get rid of the dead gas in the unswept portion of the cylinder by lapping the valves, i.e., allowing the inlet valve to open a few degrees before the exhaust valve closes, so taking advantage of the inertia of the exhaust gas to draw the new charge across the piston tap.

Other types of valves have been introduced from time to time such as the disc, plug, and piston types, but the only one attaining any degree of popularity, and this only in one field, is the sleeve valve.

The sleeves are reciprocated by small eccentrics, the ports registering at the desired points in the stroke.

Compression Pressures.—It is found an advantage upon theoretical grounds to use as high a compression pressure as possible, the limit being reached when spontaneous combustion takes place, upon the compression stroke, due to the heating up of the charge. This critical pressure varies with different fuels, being low for fuels containing a large hydrogen content. The general design of an engine also influences the pressure permissible, as will be easily seen, engines with ample water jackets and no overheated local spots in the cylinder permitting the use of a higher compression ratio.

The volumetric efficiency of an engine, spoken of under the heading of valves, is represented by the equation—

$$\frac{X}{Vp}$$

Where— X = Charge actually inducted.

Vp = Volume swept out by the piston.

The compression ratio which plays such a vital point in engine design is given by—

$$\frac{V + V_p}{V}$$

Where— V = Volume of compression space.

In settling a suitable compression ratio there is not only the critical spontaneous compression pressure to contend with, but also the rate of flame propagation throughout the mixture, which varies with different fuels. For instance, acetylene gas and also paraffin mixtures explode with much violence and often cause severe knocking, which has led some makers to introduce water with the mixture, by means of a drip, in order to tone down the explosion when the engine is under full load.

The compression of the charge is approximately adiabatic, the expression for which is

$$PV^n = \text{Constant.}$$

The compression pressure is given by the formula

$$P_c = P\left(\frac{V + V_p}{V}\right)^n$$

Where— P_c = Compression pressure absolute.
P = Pressure before compression.

As the expression $\frac{V + V_p}{V}$ is the compression ratio which can be represented by R, the compression in terms of it is given by—

$$P_c = PR^n$$

The pressure P of the charge before compression is governed by the volumetric efficiency, it being in well-designed engines about 14.2 pounds per square inch at low speeds and 11 to 13.75 pounds per square inch at normal speeds, the former figure being for a moderately well-designed high-speed automobile-type engine and the latter for a well-designed slow-speed gas engine.

Other everyday examples fall somewhere between 12.7 and 13.5, 13.1 being a fair average.

The value of the exponent N is in the region of 1.3; a fairly accurate representation of its value being 1.37 for the compression stroke and 1.32 for the expansion line.

The following table gives some of the successful pressures used:

Fuel.	Engine.	Pressure lbs. per square inch gauge.
Paraffin	Four-cycle boat	65
Petrol	Two-cycle automobile	70
Petrol	Four-cycle automobile	85
Illuminating gas.	Four-cycle gas	80
Natural gas	Four-cycle gas	100
Producer gas	Four-cycle gas	130
Blast furnace gas	Four and two cycle	160
Oil	Semi-Diesel boat	150–210
Alcohol	Automobile type	200
Diesel	Two-cycle Marine	450 and upwards
Petrol	Aero engine and racing automobile	130

The following table is also interesting as it gives an idea of the maximum explosion and mean effective pressure prevailing:

Engine.	Explosion pressure gauge.	M.e.p.
Gas engine, four-cycle	450	...
Diesel engine, four-cycle	685	151
Diesel marine, two-cycle	650	110
Automobile	300	84
Automobile	295	81
Aero engine, air-cooled	432	90
Aero engine, water-cooled	454	93

Efficiency.—A great point in favor of the adaption of internal-combustion engines is the high thermal efficiency obtainable, the following table giving the approximate growth in efficiency of the various prime movers from early times to the present date:

Prime mover.	Indicated thermal efficiency per cent.
Boulton and Watt condensing	3.8
Lenoir gas engine	4.0
Cornish engine	9.0
Four-stroke cycle, on inception, gas	16.0
Triple-expansion condensing	18.0
Oil engine	22.0
Parson's turbine	23.0
Petrol engine, automobile	25.0
Gas engine	28.0
Diesel two-cycle	33.0
Diesel four-cycle	38.0
Still engine (said to be)	44.0

The losses in the internal-combustion engine are variously estimated by different authorities, but the following is a fair average:

Loss.	Per cent.
In exhaust	52.5
In water jacket	15.3
Mechanical loss	4.7
Power at crankshaft	27.5
	100.0

Design.—With regard to the design of this type of engine it may be said that the subject is now of a more settled nature compared with a few years ago when engines were built by rule of thumb methods. Results are now foretold with considerable exactitude, all stresses being fairly accurately computable, a great amount of research work having overcome numerous difficulties.

A small amount of trouble is still met with in connection with the heat gradient in cylinder walls and pistons, resulting in the occasional cracking of these parts from unequal expansion, this being confined principally to the larger sizes.

Many makers are now constructing engines with cylinders set desaxialy, *i.e.*, setting the cylinder not directly over the crankshaft, thus equalizing the pressure upon the cylinder walls the amount of setting being reasonable, to avoid complications in other directions.

Balancing has also received considerable attention since it became such an important factor in high-speed engine design, many makers carrying this out with great care, installing apparatus for accurate static and dynamic balancing.—"The Steamship."

OIL AS A FUEL FROM THE PRODUCER'S VIEWPOINT.*

By Henry Thomas,

Combustion Engineer, the Sun Company, Philadelphia, Pa.

ORIGIN.

Very little is known of the origin of petroleum, but there are several theories held by various authorities.

The Organic theory is the one most generally accepted and the one held by the greatest number of authorities.

According to this theory, the petroleum is formed by the action of time, heat, and pressure, also probably salt water, on the remains of marine animal and vegetable matter.

One of the principal reasons for this theory is the very frequent occurrence of petroleum in extinct sea beds, and at various places adjacent to present sea shores. It would seem, at least, that its origin must in some way be influenced by salt water.

Some authorities hold that the asphalt base oils are derived from animal matter and the paraffin from vegetable matter. Still, adherents of the organic theory hold that different qualities of oil are due to differences in pressure, heat, extent of its migration, etc.

The Inorganic theory is based on the effect of water on carbides yielding hydrocarbons. It seems quite clear, however, that no important petroleum field derived its hydrocarbons from purely inorganic sources.

The Terrestrial Vegetation theory is based on the action of heat and time on peat, lignite, and coal. Coal fields, however, are not usually adjacent to oil fields, and generally do not occur in such locations as to suggest this origin.

EARLY HISTORY OF PETROLEUM.

For many centuries references have been made to oil and gas found in various parts of the known world. Herodotus in 475 B. C. describes the oil pits near Babylon. The ancient records of China and Japan are said to contain many allusions to the use of natural gas for lighting and heating. Marco Polo refers to the oil springs of Baku towards the end of the Thirteenth Century. The earliest reference of American petroleum occurs in Sir Walter Raleigh's account of the Trinidad pitch-lake in 1595, while in 1632 the account of the visit of Joseph d'Allion to the oil springs of New York was published in Sagard's "Historie du Canada." A Russian traveler, Peter Kalm, in his work on America published in 1748, showed a map of the oil springs of Pennsylvania.

The more modern industrial development of the petroleum industry began about 1854, in which year the Pennsylvania Rock Oil Company was formed. Its operations were unsuccessful, and in 1858 certain of its members formed the Seneca Oil Company, under whose direction Drake, in 1859, drilled at Oil Creek, Pa., the first oil well, and on August 28th,

* Delivered before the Joint Meeting of the American Society of Heating and Ventilating Engineers and the American Society of Mechanical Engineers, December 11, 1919, in the auditorium of the Engineers' Club of Philadelphia.

at a depth of 69 feet, struck oil. This well produced 25 barrels of oil per day for some time, and at the end of the year had dropped to 15 barrels per day.

The production of crude petroleum in the United States was officially reported to be 2,000 barrels for 1859; 4,215,000 barrels in 1869; 19,914,146 in 1879; 35,163,513 barrels in 1889; 126,493,936 barrels in 1906; 355,937,716 barrels in 1918.

For about ten years Pennsylvania was the one great oil-producing section of the world; but since 1870 oil has been discovered and produced in practically all parts of the world.

WORLD'S PRODUCTION OF PETROLEUM.

The world production of petroleum for 1918, according to report of the Department of the Interior of the United States Geological Survey, was 514,208,715 barrels of 42 gallons, which was produced by the following countries in the order of their quantity:

	Barrels of 42 gals.
United States	355,927,716
Mexico	63,828,327
Russia	40,256,182
Dutch East Indies (includes British Borneo)	12,846,365
Rumania	8,730,235
India (estimated)	8,000,000
Persia	7,200,000
Galicia	5,591,620
Peru	2,536,102
Japan and Formosa	2,449,000
Egypt	2,079,750
Trinidad	2,000,000
Argentina	1,321,315
Germany	711,200
Canada	304,741
Venezuela	190,080
Italy	35,953
	514,208,715

Oil is found in the earth at varying depths. In Pennsylvania wells usually vary from 200 to 1,000 feet, while the deepest well ever drilled, which is located in Clarksburg, W. Va., is 7,579 feet. In the Indiana and Illinois fields, wells vary from 750 to 1,900 feet; the Mid-Continent fields run from 800 to 1,500 and up to 3,500 feet. Gulf field, 800 to 1,500 feet. California field, 2,000 to 4,000 feet, and some up to 5,000 feet.

The Russian wells are 500 to 2,000 feet deep. The Borneo wells vary from 1,000 to 2,000 feet, and the Mexican wells, 1,000 to 2,500 feet.

OIL WELL DRILLING SYSTEMS.

There are two general systems of drilling oil wells, the cable system and the rotary system.

The Cable System is used where many hard rock formations are to be drilled through, while the Rotary System, which is much faster, is used where clay and soft rock formation are encountered.

The cable system consists of a drilling tool or bit suspended on a cable. This tool is raised and lowered by the cable which is carried over a pulley and attached at the other end to a walking beam. The impact of the tool carries it through the rock and other formations.

The *Rotary System* consists essentially in the use of rotary hollow drilling rods or casing to which is attached the drilling bit and through which a continuous stream of water under a pressure of 40 to 100 pounds per square inch is forced.

In many fields there is sufficient gas pressure or hydrostatic pressure, that when the oil-bearing rock, which may be 5 to 25 feet thick, and which is generally a sandstone or other porous rock, is reached with the drill, the oil is forced under very high pressure, possibly 800 to 1,000 pounds per square inch, in which case it would blow the tools, rods, etc., forcibly out of the well.

Where the flow is very low, with practically no pressure, the well is often torpedoed to break up the oil-bearing strata to increase the flow.

The cost of drilling wells varies greatly. Wells of 3,000 to 4,000 feet, such as the Texas, California, and Mexican wells, will cost from $40,000 to $60,000 up to the time they are producing.

PRODUCTION OF OIL IN THE NORTH AMERICAN FIELDS.

The production of the Pennsylvania or Appalachian fields, which includes Eastern Ohio and West Virginia, for 1918, was about 26 million barrels. This oil has a gravity of about 40 to 48 degrees Baumé, and is of a paraffin base.

The Lima-Indiana and Illinois fields produced 19 million barrels. The gravity is 35 to 41 degrees Baumé, and is a paraffin base.

The Mid-Continent field, which includes Oklahoma, Kansas, and Panhandle Texas, produced 186 million barrels. The gravity runs 27 to 40 degrees Baumé, and is for the most part of asphalt base, although considerable is of paraffin base.

The Gulf field, which includes Louisiana and the Gulf Coast, produced 22 million barrels. The gravity runs 14 to 25 degrees Baumé, and is asphalt base.

The California field produced 100 million barrels and is for the most part asphalt base, although there is some paraffin present. The gravity is from 12 to 30 degrees Baumé.

The Mexican fields produced 63 million barrels. This is all asphalt base and the gravity runs from 10 to 20 degrees Baumé.

CONSUMPTION OF FUEL OIL IN THE UNITED STATES.

All of these fields contribute to the supply of fuel oil, which is used for various purposes. It is estimated that 75 to 150 million barrels of oil per year are used in the United States for fuel purposes. This includes the fuel oil distillates, gas oil, reduced crudes, and crudes. While it has been the custom in years past, especially in California and Texas, to burn considerable crude oil just as it was received from the ground, this practice has very materially decreased the last few years, partly due to increased price of crude and due to the great demand for gasoline. In fact, a great many of those who were users of Domestic crudes in California, Texas and Louisiana, are now buying Mexican oils, and the railroads, such as the Southern Pacific and the Santa Fé, are now using Mexican oils.

While a great deal of fuel oil in the form of distillates is derived from oils of the various fields in the United States, the greater share of such oils are used for furnace work and various heating processes in the manufacture of iron, steel, enamelling, drying, etc., and in the manufacture of gas.

A great deal of the California production is used for fuel purposes, but is used quite largely in California and for marine purposes on the Pacific coast and by various railroads operating in California.

MEXICAN OIL FIELDS.

For a fuel oil for boiler purposes along the Atlantic coast, we must look to the Mexican fields for this supply.

It will be noted from the figures previously given, that with a world production of petroleum of 520,000,000 barrels Mexico stands second with a production of 63 million barrels in 1918, and about 80,000,000 for 1919, or about 15 per cent of world production.

The history of oil in Mexico is rather a remarkable one. Oil traces were found in Mexico west of Tampico in 1900, and oil was first struck in 1901 by Mr. E. L. Doheny. A few years later a deep well was drilled which produced 10,000 barrels per day. This well is still producing at the rate of 800 barrels per day. Many wells with very large production have been brought in in Mexico.

The largest well ever discovered is reported to have produced 1 million barrels per day, but the rate continued for only five days, and a very large share of the oil was wasted as it could not be controlled or proper storage provided.

The second largest well, the Cerro Azul, was brought in in 1914, and produced 264,000 barrels per day, and is still in operation, although not at this high rate. In 1910 the Potrero No. 4 well was brought in and since that time has produced considerably over 100 million barrels. Most of the better wells produce from 10,000 to 60,000 barrels per day. The number of producing wells in Mexico in February, 1919, was 299, and there were 114 drilling. Nearly 500 wells had been abandoned as they had proved to be dry holes, while a few were exhausted.

PHYSICAL PROPERTIES OF MEXICAN OIL.

There are two regions in Mexico in which the oil is of quite a different nature. The Panuco River Valley, which lies quite near Tampico, produces a very heavy oil of about 10 to 13 degrees Baumé. This field produces about 80 per cent of the total. The Tuxpan field lies further south and near the Tuxpan River. This produces an oil of about 19 to 20 degrees Baumé, and amounts to about 70 per cent of the Mexican production. The oil from the Panuco region is extremely heavy and very viscous, which makes it very difficult to handle in pipe lines. It contains practically no light distillates and only a limited quantity is put through any topping or refining process. The Tuxpan oils, on the other hand, contain 10 to 15 per cent of the light distillates, much of which is gasoline. A considerable quantity of this oil is put through a topping process at refineries in Mexico, while much is shipped to the United States in its crude form and put through the topping process at the various refineries along the Atlantic and Gulf coasts.

The topped oil or reduced crude which is run down to about 14 to 15 degrees Baumé is that used almost exclusively for fuel for boiler purposes. This is an oil which is especially suited for boiler fuel, being much better than the crude from which it is derived. This is because the flash point has been raised by the taking off the light distillates, making it a much safer oil to handle and store. It is a cleaner, more uniform oil, because the water, sediment and other impurities are much reduced in the topping process. The test of this oil should run—Flash, 200 degrees F. or higher; Viscosity, about 330, Saybolt at 200 degrees F.; B.t.u. per pound, 18,400. B.t.u. per gallon, 149,000. The analysis of the oil shows about 83.5 per cent carbon, 11.3 per cent hydrogen, 1 per cent oxygen, 4.2 per cent sulphur.

MEXICO'S OIL PRODUCTION.

While the actual production of the Mexican fields for 1919 will run from 80 to 90 million barrels, this does not really represent the maximum or possible output, as the potential production is far in excess of the actual. It has been estimated by some of the geologists in this field that the potential production will run 1 million barrels per day, and the Mexican Petroleum Department estimates it at over 2 million barrels. At present about 175,000 barrels are produced. The geological formations would indicate that there is every possibility of other fields yet to be discovered which will be equal or better than those known. Even the fields already known have been but touched, as the number of wells drilled would indicate.

Several companies are preparing to spend up to 100 million dollars at present in the further development of this field.

The present production is limited almost entirely by transportation facilities. There is, in spite of the comparatively large numbers of tank steamers built in the last few years, still a very decided shortage to meet the demands of the oil-carrying trade.

INCREASING DEMAND FOR FUEL OIL.

There is a growing demand for fuel oil in all parts of the world; there is a very steady and permanent increase in its use for the merchant marine and naval vessels. Over one-half of the vessels under the Shipping Board are oil burners, while a very large share of the naval vessels of the United States and all the new ones use oil. This is also the case in the British as well as other foreign navies.

When it is considered that the exports of coal from England prior to the war were 70 million tons per year, it is now below 20 million tons, and that in 1919 it is estimated that there is a shortage in world coal production of 100 million tons, it is not strange that the supply of oil does not meet the demand.

Of the 326 million barrels delivered to the refineries in the United States in 1918, about 75 million barrels were consumed in the domestic market for fuel, and it is quite probable that for all fuel purposes nearly double this quantity is consumed.

As soon as the present shortage of tank steamers is relieved, we believe the supply of Mexican oil will be much more nearly equal to the demand.

FUTURE OIL SUPPLY.

The question of the future supply of oil is one which is continually brought up and one which is very difficult to answer conclusively. There has been a gradual increase in the world production of oil, but the demand has usually kept pace, and in some cases gained on the production. One item, that of gasoline, will illustrate the demands being made on the petroleum industry. Based on the 6 million automobiles now in existence, it requires about 100 million barrels of gasoline per year for this purpose alone. It is estimated that this amount will be doubled or tripled in the next five or ten years.

Some of the more recent estimates of the United States Geological Survey give the quantity of available oil in the ground at the end of 1918 in the United States as 6,740,000,000 barrels.

In addition to the deposits of natural oil in the ground, there is another source which gives some promise. The United States Geological Survey estimates that in Colorado, Utah, Wyoming and Nevada, there are deposits of oil shales in thicknesses of 3 feet or more, capable of yielding 25 gallons or more of oil per ton, sufficient to produce at least 75 billion barrels of

oil. According to report, this oil can be produced for 1½ cents to 2 cents per gallon. This is a high-grade oil, suitable for refining purposes. If 33 per cent of this quantity were turned into fuel oil it would be equal to 50 times the amount of the world production of petroleum for 1919.

ADVANTAGES AND USES OF OIL.

Probably next to the question of the supply of oil are those of the advantages of oil for fuel and the methods of using it.

Some of the advantages of oil as a fuel for boilers are:

1. Higher efficiency of boiler and furnace.
2. Absolute control, with ability to carry light loads as well as heavy overloads.
3. Uniform furnace conditions as regards fuel and air supply, giving minimum variation in steam pressure and furnace temperature.
4. High average boiler capacity.
5. Adaptability for banking fires for short or long periods, with low cost of same.
6. Elimination of unsatisfactory labor conditions in the handling and burning of fuel.
7. Reduced cost of furnace and boiler repairs, also elimination of machinery required for other fuel.
8. Low cost of handling and storage.
9. Uniform grade and heating value of fuel with no loss in storage.
10. Low cost of equipment required with practically no upkeep cost for same.
11. General cleanliness and absence of smoke.
12. Fires can be started or shut down quickly and shut off entirely in case of emergency.

ADDITIONAL ADVANTAGES FOR MARINE PURPOSES.

1. Quick bunkering either from shore or barge under any weather conditions.
2. Increased steaming radius for a given storage space or deadweight.
3. Utilization of space otherwise not available, i.e., water bottom.
4. Increased speed due to better steaming conditions.
5. Much improved boiler room conditions.

OIL-BURNING EQUIPMENT.

For stationary plants burning a heavy fuel oil the equipment required consists of storage tank, pump set for delivering the oil from the storage tank to the burners, the heater for raising the temperature of the oil, and the burners for atomizing the oil. For the Mexican reduced crude it is necessary to provide heating coils in the storage tank to maintain the oil at a temperature of 80 to 90 degrees F., at which temperature it can be handled without difficulty through the suction lines to the pump.

The size and type of storage tank to use for this purpose will depend largely on the size of the plant, the distance from the source of supply, and the method of receiving the oil; that is, whether it be by barge, railroad tank car, or tank trucks. A supply sufficient for a week's run is as low as would be safe under any circumstances, while many plants would want to maintain at least a month's supply.

In a plant of 500 boiler horsepower running ten hours per day, it would require about 10,000 gallons of oil per week. A plant such as this, if near the source of supply, could operate with one tank of 12,000 to 15,000 gallons capacity, if delivery was made in tank cars, but it would be a very risky matter. It is much better, if possible, to install at least two

storage tanks. This allows for the filling of one tank while the other is being used to supply the burners, and also allows for the cleaning, inspecting, and repairs when necessary without the necessity of shutting down.

In general, horizontal cylindrical tanks of from 10,000 to 20,000 gallons each, placed underground or in pits, work out more satisfactorily and more economically than other forms of tanks up to a total capacity of about 100,000 gallons. Above this quantity vertical tanks of 30 feet in diameter and up could be used.

In receiving oil in tank cars and barges, it is necessary to heat the oil in order to discharge. The barges and tank cars are equipped with heating coils so that all that is necessary is to provide a steam connection for this purpose.

OIL-BURNING SYSTEMS.

There are in general use two systems of burning oil for boiler use.

First, *the Steam Atomizing System,* in which oil is pumped to the burners at a pressure of 50 to 75 pounds per square inch and a temperature of 110 to 140 degrees F. Steam at boiler pressure is used to atomize the oil at the burner. The pump is usually operated by steam and the exhaust is used for heating the oil in the heaters and storage tank from which the oil is drawn.

Second, *the Mechanical Pressure System,* in which the oil is pumped to the burners at a pressure of 50 to 200 pounds per square inch and a temperature of 200 to 275 degrees F. The burner is entirely different from the steam atomizing type, as no steam is used at the burner. Oil only is delivered to the burners; and the atomizing is brought about by the high-temperature oil being forced through the small orifice in the burner tip under high pressure.

Both of these systems are used successfully on all types of boilers, but we will not go further into the merits of these two types of burners here, as no doubt the speaker following will discuss this subject.

We would say but a word regarding burner installation, and that is that the proper furnace arrangement is of greatest importance. A burner is required which will properly atomize and handle the oil, but without the proper furnace arrangement to thoroughly combine the air and the atomized oil, it is impossible to secure the best results.

BOILER CAPACITIES.

Tests are of much value in giving comparisons of oil with coal, but the average results day in and day out are those that are of greatest importance.

There are thousands of hand-fired plants as well as a great many stoker-fired plants, which are operating at a very low over-all efficiency; that is, the efficiency considered over a month or a year's time. This condition can be very greatly improved by the use of oils, as greater capacity can be secured, thus cutting down the numbers of boilers in service and so reducing the losses. Also, the banking cost will be very materially reduced and still further gains are made due to cleaner boiler heating surfaces.

The principal difference in efficiencies secured with oil and coal under good average conditions is due to more uniform furnace conditions which can be maintained with oil, thus allowing the quantity of excess air to be very materially reduced.

In this connection there is a point which is sometimes overlooked in making a comparison. With anthracite coal, the maximum theoretical CO_2 which can be secured is 19.6 per cent. With bituminous coal this will run about 18.8 per cent. With the average oil this will run 15.5 per

cent. This should, of course, be taken into consideration when efficiencies based on CO_2 readings are considered.

CALCULATION OF FUEL COST.

A fair comparison of total cost can only be made when everything entering into the operation of a boiler plant is considered. This should include: Cost of fuel delivered in plant or on the rail; cost of unloading; cost of storing; of rehandling; of delivering to bunkers or in front of boilers; of firing the boilers; of taking out and disposing of ashes; the cost of cleaning out furnaces, economizer pits, etc.; the investment and maintenance cost of the equipment required to handle the fuel, and also the investment and maintenance cost of the actual boiler horsepower required to carry a given load with each fuel.

There are many plants using coal that have a cost of $2 to $3 per ton of coal burned for the handling, firing, and disposing of the ashes of that coal. There are a great many hand-fired plants that do not average, over their working period, more than 50 per cent of their rating, thus requiring an investment and maintenance cost of double that necessary if boilers were run at an average full load rating.

LIMITATIONS OF LIABILITY.

Oil is without doubt an ideal fuel. It is meeting in many sections a great need, but we must realize that the supply is not without limit.

The supply of oil as a fuel is by its nature a zone proposition. From the points of distribution along the coast the oil can at a given price meet coal or other fuel. The area over which this can be done is limited, due to the cost of transportation from this distributing point.

Oil can replace coal in certain localities, but can replace only up to the limits of the oil supply.—"The Journal of the Engineers' Club of Philadelphia."

OIL AS A FUEL FROM THE CONSUMER'S VIEWPOINT.*

By E. H. Peabody.

Babcock and Wilcox Co., New York City.

In the question of oil burning there is a great deal of similarity between the points of view of the producer and the consumer. Both have to get a supply of oil and both have to dispose of that supply. So far they are together, but there is this difference, that the consumer helps the producer to get rid of his oil, but has no one but himself to help him get rid of it. By that I mean that while the consumer can get advice, and a lot of it—some of it bad—he must depend on his own efforts, his own organization, and his own supervision in order to get the best results from that oil.

Anybody can burn oil. In fact, a piece of pipe can be flattened in such a manner as to give satisfactory results in the way of an atomizer. It is only, however, when it is attempted to cut down the excess air—which is the *bete noire* of combustion because it carries away so much heat—it is only when refinements of reducing that excess air are gone into, at the same time obtaining the proper economy and necessary capacity, and avoiding trouble with the boiler heating surfaces, which lead to high maintenance costs, that the expert is needed; and it is very important,

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* Delivered before the joint meeting of the American Society of Heating and Ventilating Engineers and the American Society of Mechanical Engineers, December 11, 1919, in the auditorium of the Engineers' Club of Philadelphia.

particularly in these days, when conservation is so necessary and when the oil supply appears not to be sufficient for our needs, that it is seen to that fuel oil is burned at maximum efficiency.

In the previous paper, Mr. Thomas very well noted advantages of burning oil. The consumer realizes them at once, but at the same time two questions come to his mind immediately—two paramount questions. First, can he obtain oil in the necessary amount and with the necessary regularity? and, second, what is it going to cost compared with coal, or whatever may be his regular fuel?

Now, I do not know the answer to the first question, although, from what Mr. Thomas tells us, it would appear that there is going to be an adequate supply. I hope that this is true, because it is the ideal fuel.

As to the question of cost, that depends very largely upon local conditions. There is the great and today the very important factor of labor saving in connection with the use of oil. In the first place, the production of oil at the wells takes less labor than the production of coal, and we have very recently been going through one phase of this fuel question, and have seen what labor means in that connection. In the second place, there is always a great labor saving in the operation of an oil-fired plant. There is no coal passing, no removal of ashes, a smaller number of firemen, all of which are in favor of oil, and must be very carefully considered. Each job is, however, a particular problem in itself and no generalities can be made.

Mr. Walter McFarland has noted a very interesting little comparison, which would give a rough idea of the relative costs of oil and coal, *not* counting the labor saving, but taking into consideration the fact that with oil better boiler efficiencies are obtained. Although like every empirical formula, it is only approximate, since the quality of the coal and the quality of the oil influence the accuracy of the result, McFarland's rule is very handy for rough calculations, and is as follows: *When the cost of oil in cents per gallon equals one-half the cost of coal in dollars per long ton, the cost of fuel for producing a certain amount of steam is approximately the same.* This means that two-cent oil is equal to four-dollar coal; four-cent oil is equal to eight-dollar coal, etc. Here is a rough basis to start with, although you must remember that the great factor of labor saving comes in as an additional consideration in favor of oil.

The history of oil burning is very interesting. In the early days of oil production, to which Mr. Thomas has referred, the practice was to put oil in an ordinary bowl or pan, and by adding sufficient heat, get it ignited and then allow it to burn on the surface. That system is still in vogue today for certain purposes, but there is very little flexibility in this method, and a very limited capacity. It is not suited to boiler purposes and power purposes. In passing, I might also refer to the method of burning oil by means of a wick, which we find in the oil lamp, the limitations of which are as apparent as those of the bowl or pan system.

The most satisfactory way by far and practically the only method for burning oil for power purposes is to produce a spray. There is another method which, however, is in just the same class as the kerosene lamp, and this method consists of the conversion of the oil into a gas before admitting it to the furnace. This method has been patented, but not used successfully under general conditions, so that the spray method, whereby oil is mechanically divided into very small particles, and then injected into the furnace, is the only system recognized today as suitable for obtaining power.

There are different ways of making sprays. First, there is the method of using an atomizing medium, such as steam or compressed air issuing rapidly from an orifice, so that the oil, which is mixed with the jet of steam or air, is sprayed into the furnace from this type of burner. The

air and steam atomizer are very closely allied—in fact, almost identical—and in both cases are used in connection with inside and outside mixers.

There is another and radically different type of the mechanical atomizer, which consists of an apparatus which gives the stream of oil a rotary motion inside the tip before allowing it to be projected through the burner's orifice and converting the stream of oil into a fine spray, conical in shape.

In this connection, it might be well to emphasize what Mr. Thomas has so well said, that the most satisfactory results depend on the furnace rather than the burner, and on the method of admitting air and reducing the excess of air.

It might also be well to mention that in the choice of burners (bearing in mind that they are only a minor part of the equipment) it must be borne in mind that a burner which does not give a good spray is unsatisfactory. Another very important feature to be considered in comparing burners is the mechanical design, with particular reference to simplifying the repairs and cleaning of burners, this latter point alone sometimes being the decisive factor in the selection of the burner.

Illustrations were shown of various types of steam atomizers, including round and flat flame inside and outside mixers; also various types of mechanical atomizers. These were followed by illustrations of various types of furnaces, and explanation of reasons for using the "back-shot" burner. The use of the mechanical atomizer was explained, particularly in its application to marine work, and illustrations were shown of the White-Forster boiler installed at the Fuel Oil Testing Plant, League Island, on which some new high records for efficiency and capacity were made by the Navy Department, and, with the permission of the Department, some diagrams illustrating the results obtained were shown.

DISCUSSION.

MR. MCLEOD: When oil is burned as a fuel instead of being conserved for use in manufacturing purposes, such as making linoleum, is it not being consumed in a manner which probably will be regretted in later years?

MR. THOMAS: There is no question but that there is a great deal of oil used as fuel which probably could be used for other purposes. The more refined oil, that is, the distillates, which are being used for fuel purposes, more especially for general heating purposes, undoubtedly could be used in manufacturing processes. I do not know, however, that these oils have any especially high commercial value for such purposes.

The oil to which we look at present for fuel uses, namely, the Mexican oils, have a smaller value for refining processes, for lubricating oils and similar purposes than most other oils with which we are familiar. For these reasons there need be no occasion to feel, when we burn such oils, that we are extravagantly using up valuable products.

MR. C. H. BROMLEY: Are Mr. McFarland's ratios calculated upon a heat value basis, or are they the result of actual costs? The point I wish to bring out is this, namely: oil lends itself to such perfect control as compared with coal that one can more nearly approach the theoretical quantity of air required, with the result that any comparison based on heat value would work out to the disadvantage of oil, particularly if the combustion volume is suited to the boiler rate or the number of B.t.u.'s liberated in a given time.

MR. PEABODY: Mr. McFarland's basis of calculation was on approximately 14,300 B.t.u. per pound of coal and 18,600 B.t.u. per pound of oil, consideration also being given to the fact that better boiler efficiency is obtained from oil than from coal. It must be borne in mind, however, that this rule affords but a rough approximation, and should be applied to any particular case with great discretion. Remember, also, that no account is taken of labor saving.

MR. JERMON: What is the relative amounts of steam required by the steam and mechanical atomizers?

MR. PEABODY: The best steam atomizer requires from 1½ to 2 per cent of the output of the boiler to atomize the oil, although consumption may run very much higher if the fireman is careless. Some tests have been made at less than 1½ per cent, but I do not think that a fair average consumption would be smaller than 1½ to 1¾ per cent.

The mechanical atomizer, on the other hand, makes no direct use for steam for atomizing. It requires a small additional equipment over that used for the steam atomizer, in that the oil pressure is higher, usually from 150 to 200 pounds. There is some extra steam used in the pump; the amount, however, is not very great. Some additional steam also is required in the heater, because of the fact that the oil must be carried to a higher temperature to atomize it mechanically, but the figures we have show that this consumption is less than 1½ per cent. Undoubtedly, there is some saving in steam consumption with the mechanical atomizer, but the important factor is that the mechanical atomizer takes out of the fireman's hands the possibility of wasting 6 or 7 per cent of the output of the boiler.

MR. W. A. STEIGER: Mr. Peabody stated that a Scotch or fire-tube boiler would require a differently designed mechanical atomizer than would a water-tube boiler. Does this statement refer to the angle of the spray only?

MR. PEABODY: The angle of the spray is very intimately associated with the degree of atomization obtained in a mechanical atomizer. When I made that statement with regard to Scotch boilers, I had reference to a mechanical atomizer which produces a very different spray—a very narrow angle spray, which might produce sparks, *i.e.*, heavy drops of oil, which almost reach the floor of the furnace before consumption. Such a burner might be able to give fairly satisfactory results in a furnace where there is only one burner, and all the gases travel back to the rear, thus affording a very large combustion space. That same burner might do pretty well in a Scotch boiler, but when you put it into a furnace of the express type, where the flame goes partly to the rear and partly sidewise, it is necessary to have much greater refinement than a wide angle spray gives, so that a burner which would work all right in a Scotch boiler would not work at all in the express type. The result would be smoke, pulsation, carbon and unlimited troubles.

MR. LEWIS: For land boilers of the injection type I understand that the oil on being sprayed in carries along with it enough air for combustion for ordinary ratings. Is that true for the overrating of boilers such as are obtained in public service power plants, where 200 per cent ratings, and possibly larger, are obtained with oil-burning equipment?

MR. PEABODY: We do not calculate at all on the injection action as tending to introduce air for combustion. The round-flame burner set in a certain way does have some effect, but it is not to be depended upon to any great extent. A strong natural draught or forced draught would have to be provided for a power-house requiring 200 per cent. above rating. There is this consideration, however, that the choice between a mechanical and steam atomizer for a stationary plant must be considered. Each type has its field. In the first place, a steam atomizer is a cheaper installation. It is not necessry to remove grates. If the plant has been coal fired, steam atomizers may be installed through the fire door and fire brick layed over the grate bars, allowing the air for combustion to come up between the bricks, thus effecting a comparatively inexpensive installation, as far as the burner goes. On the other hand, while the mechanical atomizer requires a larger installation cost, since the grate bars must be removed and the ashpit lined with fire brick, it has a very distinct advantage with heavy loads.

As far as the steam atomizer has been developed, it is good for perhaps 250 per cent rating. With the mechanical atomizer, we are not limited in the number of burners that may be put in, but only by the size of the boiler front. (We have 11 and 16 burners on the White-Forster boiler at the United States Fuel Testing Plant.) The result is that with forced draught, or with a high natural draught, the capacity to which we can force the mechanical atomizer, is very much higher than can be obtained with the steam atomizer.

MR. BROMLEY: In changing from coal to oil, and, at the same time, carrying the boiler ratings that may be necessary, the question of combustion volume comes up—the combustion volume needed to liberate a given number of heat units from coal as compared with the combustion volume needed to deliver a number of heat units from oil.

MR. PEABODY: The effect of furnace volume in burning oil is of very great importance—of much greater importance than it is in burning coal, because it corresponds more nearly to the grate surface.

In a coal installation we have a given draught and a given grate area. We know that we can burn coal at a certain rate of combustion, and while furnace volume is important in the case of a volatile fuel, it is rather dependent on the fuel—on the class of the coal—rather than on the actual consumption of the coal. In other words, coal can be burned without the volume, the degree to which you burn the gases being the major factor. A long flaming volatile coal requires a good deal of furnace volume, and here the grate comes in as an important factor. In the case of oil, a furnace of given volume and given draught can burn a definite amount of oil per cubic foot of furnace volume. If the volume is increased more oil can be burned with the same draught. More commonly, however, the draught is increased, and then we may burn more oil per cubic foot of furnace volume.

I do not know that any definite relation exists between coal and oil in this respect. We do not ordinarily figure furnace volume with coal. We know that for volatile fuels we need a big furnace, while with anthracite a much smaller one is satisfactory. The best designers of oil burners, on the other hand, are very careful to consider the amount of furnace volume available for burning the oil. In one case, the grate is a basis of calculation (furnace volume being of minor importance); in the other case, furnace volume is of basic importance.

MR. W. J. POLLOCK: In installing oil burners, under boilers that are at the present time using coal, should the stokers be removed?

MR. PEABODY: The question of whether the stoker should be removed depends, first, on the amount of capacity which must be obtained from the plant, and second, on the type of burner.

We have two types of burners, the steam and the mechanical atomizer. One gives a round flame, and the other usually a flat flame. The flat flame burner can be installed right over the stoker in many cases, providing the furnace volume is sufficient for the desired capacity. If the furnace volume and the draught are suitable, there is probably no reason for removing the stoker. With a mechanical atomizer, on the contrary, the stoker must be removed, or at least a certain height of furnace provided in order to take care of the conical flame, since all efforts to make a flat flame mechanical burner have been comparatively unsuccessful. There is another possibility, namely, that it is sometimes possible to put a burner in at the back of the setting, thus leaving the stoker intact.

MEMBER: What increase in efficiency may be expected from the use of fuel oil as compared with coal?

MR. PEABODY: The best efficiency for stokers is about 82 per cent. This is doing pretty well for coal, which requires a large installation, and, as a matter of fact, 82 per cent of efficiency is not very often obtained. On the other hand, there is no great difficulty in getting 80 per cent

efficiency from almost any kind of plant burning fuel oil, and I have seen records with this fuel, using the mechanical atomizer, showing nearly 83½ per cent efficiency. With the better class of stoker, economical consumption of coal approaches very closely the efficiency with oil, although I believe that oil has a very fair chance of giving better returns than stokers, provided, however, that the fireman attends to his job, since in the case of oil, the fireman's attention is more important than with the stoker.

MR. WINDLE: We have discussed tonight two methods for burning oil; one by the use of atomizing by steam and the other by compressed air. There is another method of burning fuel oil which is in practical use to a considerable extent throughout California. This method consists in atomizing the oil by means of centrifugal force, using a special type of cup or pan operated by an electric motor. No steam whatever is employed with the device, nor is compressed air used. Most of the applications have been made on small units (such as for house heating and in connection with boilers up to about 60 horsepower), and the claim is made that for such units the method is very practical. Now, the question is, has this type of burner any real mechanical merit?

MR. PEABODY: About 1860 a gentleman by the name of Frederick Cook invented a burner on which he obtained a patent. His device consisted of a rotating shaft with a disk on the end of it, the oil being driven off by centrifugal force, and I have no doubt it made a very satisfactory spray. This spray system disappeared from sight, as far as I can find out, until about 1902, when the Liquid Fuel Oil Board of the Navy conducted some very interesting tests at Washington, in connection with the application of fuel oil for marine purposes. Unfortunately, that Board was led, and very naturally so, to confining their experiments to steam atomizers, and hence did not go very much into the field of mechanical atomization. In their report, however, there was a chapter devoted to the mechanical burner, in which was recorded one or two experiments with rotating disks.

I was very much interested to learn some five years ago that the latter system had been introduced with great success in California for use in connection with house-heating plants. The Fess burner is of this type, and has been successfully installed in New England in a large number of plants. I believe there is a very distinct field for this type of burner, and so far as I can learn, it seems to afford a very practical way of burning oil. Since the atomizing is done mechanically, it is very attractive in a plant where there is no skilled engineer. How broad the field for this type of burner is, I do not know. I do not believe, however, that it has yet been applied to power-houses or marine work.

MR. H. A. SMITH: I would like to ask Mr. Peabody if he has ever arrived at any maximum required volume of furnace per pound of oil burned.

MR. PEABODY: Maximum capacity tests show an oil consumption per cubic foot of furnace volume of over 15 pounds per hour. That consumption, however, is very high. In ordinary work we do not go much beyond 5 pounds per hour. We find that while the large furnace is desirable and larger proportions might be employed to good advantage, a ratio of about 1 cubic foot of furnace volume to 10 square feet of heating surface gives very satisfactory results (the foregoing is with reference to marine work). On shore work, if there is plenty of room, the furnace volume might be very well increased, which would mean that the oil is being burned with less draught, but even in this class of work, the ratio of 1 to 10 seems to be about right.

MR. IRWIN: Is automatic control of oil and steam, or oil, or oil and air, desirable?

MR. PEABODY: Automatic control is a very desirable thing to aim at, and I believe it is coming. There are difficult problems in connection

with it, however, particularly with a variable load where, at intervals, it may be desirable to regulate the capacity, not only by the pressure of the oil, but by entirely shutting off some of the burners. It is here that the difficult problem in connection with automatic control is presented. In a fairly uniform load, however, the matter is much simpler, and several types of automatic apparatus are now on the market, for which successful results are claimed. Personally, I feel that none of them have reached a satisfactory development, but I do feel that this development will come before many years.—"The Journal of the Engineers' Club of Philadelphia."

PLAN FOR ELECTRIC-DRIVEN JAPANESE WARSHIPS.

The electric-driven warships of the American Navy are attracting the attention of all the navies of the world. These ships are greatly superior to the old steam engines.

Our Imperial Navy, wishing to apply this scheme to Japanese ships in the future, is now earnestly trying to make the engines. As it is not satisfactory to leave the investigation simply to civilians, the Navy proposed an investigation expenditure of several million yen in the next year's budget and decided to make a serious study of the matter.

There are now two opinions for the method of study; one is to buy small special service vessels that are electric driven from America and the other is to buy only the engines. The method of study will be settled some way between the Military Technical Headquarters and each Arsenal after the budget is approved by the Diet, but if Japan buys the engines only, it is said that these engines will be arranged to our special service vessels of about 10,000 tons for trial use.

It is said that the Asano shipyard bought not long ago motors and generators of 5,000 horsepower for about 30,000,000 yen from Sweden and they are planning to fit them to the 8,000-ton class of ship which will be finished about the beginning of next year. It is said the result is attracting considerable attention from the Navy.

England has said that she will decide on adoption or rejection of the electric drive after seeing the effect of the American Navy's experimental engines that are going to be fitted to five new battle cruisers which are now in the course of construction.—Translation from "Tokyo Nichi Nichi."

AMERICAN METEOROLOGICAL SOCIETY.

The American Meteorological Society, having for its object the advancement and diffusion of the knowledge of meteorology and climatology, and the broadening of their applications in public health, agriculture, engineering, aeronautics, industry and commerce, was organized in St. Louis on December 29, 1919.

Although no data is at hand as to the membership of the new Society, it is known that, prior to organization, about five hundred persons had indicated their desire to join when organized. A number of Army and Navy officers and a number of engineers, principally hydraulic engineers, were included in the above number.

It is understood that the Society will issue a bulletin in which will be published the papers presented at meetings of the Society.

The field to be covered by the Society is one concerning which there is at present too little generally known information, and it is believed that the new Society will aid in the spread of such needed information.

MR. E. H. PEABODY HEADS NEW CORPORATION.

LEAVES BABCOCK & WILCOX COMPANY TO ENTER OIL FUEL BURNING FIELD.

The many friends of Mr. Ernest H. Peabody will be interested to know that he has resigned after thirty years with the Babcock & Wilcox Company in order to head a New York corporation, "The Peabody Engineering Corporation," the temporary address of which is 160 Broadway, New York City. The new corporation will enter the oil fuel burning field in all its branches.

Mr. Peabody graduated from Stevens Institute of Technology in 1890 with the degree of Mechanical Engineer. He entered the employ of the Babcock & Wilcox Company in the spring of 1891 and has been in their service continuously since that date. When offered the position of Chief Engineer of the company he declined and entered the Marine Department, of which department he was the executive at the time of his resignation.

During a fifteen-year period in charge of the Department of Tests he made a special study of the burning of oil fuel. This culminated in the invention of the "Rear Shot" burner and furnace, which was adopted as a standard by the Babcock & Wilcox Company. As a pioneer in the development of the mechanical atomizer, he is the inventor of the burner that bears his name and that is widely used in the Navy and in the Merchant Marine.

His classical paper, "Oil Fuel," read before the International Engineering Congress at San Francisco, is the authority today in this field. He has long been recognized as an authority on oil fuel burning and boilers and he enters his new work perfectly equipped. His continued success is predicted.

THE TECH ENGINEERING NEWS.

The first number of "The Tech Engineering News," a paper edited and published solely by the students of the Massachusetts Institute of Technology, has been received. The number creates a favorable impression and, if it succeeds in its attempt to provide a medium for the exchange of ideas between the institute and engineers throughout the country and to bring students in closer touch with actual conditions, it will fill a long felt want.

NATIONAL MARINE WEEK AND NATIONAL MARINE EXPOSITION.

Under the auspices of the National Marine League, a series of demonstrations, centering in New York City, will be held from April 12 to April 17, 1920, under the designation of National Marine Week, to arouse interest in the merchant marine of the Untied States. Although the program is not complete, it is evident that the features arranged for the week will be varied, interesting and instructive.

During National Marine Week the first National Marine Exposition will be held at Grand Central Palace, New York, and from the names of the firms who have already arranged for space, it is believed that visitors will gain a new and wider view of the merchant marine, the manufacturers interested in it, the shipbuilding yards and the ship owners.

STERLING'S MARINE ENGINEERING CATALOG AND SERVICE.

It will be a matter of interest to members of the Society and to readers of the JOURNAL to know that Lt. Comdr. O. F. Cooper, U. S. N. (retired), and Lt. Comdr. F. W. Sterling, U. S. N. (retired), have organized the Sterling-Cooper Company, with headquarters at 141 Broadway, New York, and have entered the field of consulting and advertising engineers.

The company is divided into two main departments, the Catalog Department and the Service Department, the former being under the personal direction of Lt. Comdr. Cooper, and the latter under Lt. Comdr. Sterling. Both gentlemen are well fitted for their positions, Lt. Comdr. Cooper having had charge, during the war, of the Navy Publicity Bureau, New York City, and Lt. Comdr. Sterling by his service in the Bureau of Steam Engineering and his long service as Secretary-Treasurer of the American Society of Naval Engineers.

The prospectus issued by the company gives a concise statement of the aims of the company, outlines the annual catalog they will issue and gives a resumé of the class of work the company is prepared to handle. Their catalog, as outlined, will be a valuable source of engineering information and one for which there is a great need. The success of the new firm is predicted and their growth will be watched with interest.

BOOK REVIEWS.

ROBISON'S MANUAL OF RADIO TELEGRAPHY AND TELEPHONY. CAPTAIN S. S. ROBISON, U. S. NAVY. Fifth Revised Edition. By CAPTAIN D. W. TODD, U. S. NAVY, and COMMANDER C. S. HOOPER, U. S. NAVY. 307 Pages. THE UNITED STATES NAVAL INSTITUTE, Annapolis, Md. Price, $1.50, postpaid.

"Robison's Manual of Radio Telegraphy" was revised in the fifth edition in the fall of 1919.

Only the first five chapters pertain to electro magnetism, transfer of energy and fundamental equations of telegraphy and efficiency of various type waves, whereas the remaining twelve chapters contain interesting descriptions of the newest type of apparatus in use.

Several of these interesting items are: Spark transmitters, new arc transmitters, radio telephone transmitters, vacuum tube transmitters together with theory of the vacuum tube, new standard Navy receiving sets, various types of antennæ, including the new submarine loop antennæ, cage antennæ, underground antennæ, various balanced antennæ and multiplex receiving systems, 200-K.W. high frequency alternator for trans-oceanic work, 350-K.W. arc transmitters, radio compasses on ship and shore, aircraft transmitting and receiving sets together with aircraft compass and interesting chapters on installation, adjustment and measurements.

All the foregoing apparatus is vividly illustrated by frequent full-page photographs of actual apparatus as installed in aircraft, shore stations, etc., which, with the interesting way in which the book is written, makes this manual of great value to the layman and those interested in radio telegraphy and telephony as well as to naval electricians.

HEROES OF THE NAVY IN AMERICA. 2d Edition, revised and enlarged by CHARLES MORRIS. 347 Pages. J. B. LIPPINCOTT & Co., Philadelphia. Price, $1.50 net.

This edition has been enlarged and includes a brief chapter on the United States Navy in the World War, and also a chapter on the "Navies of the Under Sea and the Upper Air." It is an interesting book and contains many items not found in histories.

ASSOCIATION NOTES.

Meeting of Society December 30, 1919.

A meeting of the Society was held at the Navy Department, Washington, D. C., December 30, 1920, to count the votes cast for officers of the Society for the year 1920. The following were elected:

President:

Rear Admiral C. W. Dyson, U. S. Navy.

Secretary-Treasurer:

Commander J. S. Evans, U. S. Navy.

Council:

Rear Admiral B. C. Bryan, U. S. Navy.
Captain Robert Stocker (C. C.), U. S. Navy.
Commander S. C. Hooper, U. S. Navy.
Commander Kenneth Whiting, U. S. Navy.
Captain of Engineers W. M. Prall, U. S. Coast Guard.

Ballots cast showed an opinion on the part of a substantial majority of the membership in favor of holding a banquet during the year and a committee to make arrangements for this will be appointed in the near future.

FINANCIAL STATEMENT, 1919.

PUBLICATION STATEMENT.

The following statement shows the cost of producing the Journal of the Society for 1919 and the returns therefrom, with the gross profit:

	Costs.	*Returns.*
Dues		$5,777.67
Subscriptions		2,935.18
Sales		1,137.39
Advertisements		2,455.00
Exchange		1.32
		$12,306.56

Printing	$7,058.16	
Engraving	1,007.48	
Drafting	6.00	
Manuscript	910.00	
Commission	200.89	
Postage and Express	177.60	
		9,360.13
Gross Profit		$2,946.43

GENERAL PROFIT AND LOSS STATEMENT.

The following statement shows the result of the business of the Society for the year 1919 as a whole:

	Loss.	*Gain.*
Gross Profit from Publication		$2,946.43
Interest		594.59
		$3,541.02
General Expense (includes salaries)	$2,045.61	
Current Profit and Loss	311.85	
		2,357.46
Net Gain		$1,183.56

BALANCE STATEMENT.

The following statement shows the difference between the assets of the Society on January 1, 1919, and on December 31, 1919. There are no liabilities.

ASSETS DECEMBER 31, 1919.

Cash	$3,368.03
Accounts Receivable, Advertisements	1,337.50
Accounts Receivable, Dues	1,172.49
Accounts Receivable, Sales	26.83
Accounts Receivable, Subscriptions	1,122.23
Army and Navy Club Bond	1,000.00
Certificate of Deposit, Munsey Trust Co	1,020.00
Furniture	122.84
Government Bond, 1st Liberty	1,000.00
Government Bond, 3d Liberty	1,000.00
Government Bond, 4th Liberty	2,385.20
Government Bond, 5th Liberty	1,000.00
War Savings Stamps	838.00

Washington Railway & Electric Co. Bonds	4,320.00
Claim against American Railway Express Co	100.00
	$19,813.12
Total assets January 1, 1919 (Capital)	18,629.56
Net Gain	$1,183.56

Respectfully submitted,

J. S. EVANS,
Secretary-Treasurer.

An auditing committee has been appointed and accounts are now being audited.

The following members and associates have joined the Society since the publication of the last JOURNAL:

MEMBERS.

Dodson, H. L., Lieut., U. S. N.
Greenlee, H. R., Commander, U. S. N.
Mack, Albert R., Lieut. Commander, U. S. N.
Sorensen, S. K., Lieut., U. S. N.
Sullivan, T. J., Lieut., U. S. N.

ASSOCIATES.

Allison, Fred, Electrical Engineer, Ford Motor Co., Detroit, Michigan.

Brocklebank, A. P., Alberger Condenser and Engineering Co., New York City.

Doran, W. S., President, Alberger Condenser and Engineering Co., New York City.

Eyermann, Peter, Austria.

Gibson, Bruce, Chief of Engineers Dept., U. S. Shipping Board, Washington, D. C.

Ljunstrom, O., 3631 Cottage Avenue, Baltimore, Md.

Pigott, S. J., John Brown & Co., Clydebank, Scotland.

Smith, R. S., Apartment 16, 736 Park Avenue, Weehawken, N. J.

Stevens, Clarion Hazen, Room 206, 26 Broadway, New York City.

Walker, R. J., Turbinia Works, Wallsend on Tyne, England.

West, Charles C., Vice President and General Manager, Manitowoc Ship Building Co., Manitowoc, Wis.

Please do not fail to keep the Secretary advised of your address in order that your copy of the JOURNAL may reach you promptly upon its issue.

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MEMBERS.

Dodson, H. L., Lieut., U. S. N.

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Sullivan, T. J., Lieut., U. S. N.

ASSOCIATES.

Allison, Fred, Electrical Engineer, Ford Motor Co., Detroit, Michigan.

Brocklebank, A. P., Manager Condenser and Engineering Co., New York City.

Doran, W. S., President Manager Condenser and Engineering Co., New York City.

Eyermann, Peter, Attorney.

Gibson, Bruce, Chief of Machinery Dept., U. S. Shipping Board, Washington, D. C.

Ljungstrom, O., 3821 Cottage Avenue, Baltimore, Md.

Pigeon, S. J., John Brown & Co., Clydebank, Scotland.

Smith, R. S., Apartment 6, 100 Park Avenue, Weehawken, N. J.